TREASURY DEPART
UNITED STATES PUBLIC HEALTH

PUBLIC HEALTH BULLETIN No. 14

JULY, 1924

A STUDY OF THE POLLUTION AND NATURAL PURIFICATION OF THE OHIO RIVER

II. REPORT ON SURVEYS AND LABORATORY STUDIES

Prepared by direction of the Surgeon General
under the supervision of
Surgeon W. H. Frost

WASHINGTON
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A STUDY OF THE POLLUTION AND NATURAL PURIFICATION OF THE OHIO RIVER

II. REPORT ON SURVEYS AND LABORATORY STUDIES

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Section 6. BACTERIOLOGICAL STUDIES, Surgeon W. H. Frost and Sanitary Engineer H. W. Streeter

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PREFACE

The studies which form the subject of this report were begun in the latter half of the year 1913, and, as regards the collection of the data presented, were completed by the close of the year 1916. The more difficult task of assembling the data collected from several simultaneous lines of investigation in such manner as would show their interrelations was necessarily deferred, in great part, until all the data were available. It was then interrupted, in a comparatively early stage of progress, during the spring of 1917, by the necessity of assigning the entire personnel to more immediately urgent activities, following the entrance of the United States into the World War. Not until the autumn of 1919 could the organization be in part reestablished to resume work upon this report; and almost immediately thereafter it became necessary to take up new work, which has since engaged most of the personnel. In consequence, the publication of a report has been delayed far beyond anticipation. This is, however, due only in part to the above-mentioned and unavoidable interruptions. It is largely due to the fact that such analysis of the data as would serve to relate them in an orderly way has proven more difficult than was anticipated; and progress has been correspondingly slow. It is believed, however, that the facts presented have lost none of their pertinence by the delay incident to the attempt to present them in more succinct and coherent form; and it is hoped that their significance has been made somewhat clearer.

As regards authorship, the study has been an undertaking to which a comparatively large number of people have contributed; and though the work of actually preparing the report in its present form has devolved largely upon those whose names appear as authors of the several sections, the report represents, in fact, the product of an organization working as a unit. Indeed, a very large share of the most laborious work in compiling as well as collecting the data used has been done by those whose names do not appear as authors; and although individual acknowledgments for specific contributions can not be made, the authors desire to make grateful acknowledgment to all their associates.

We also desire to acknowledge the very substantial assistance rendered by those who were associated with the work in the capacity of consultants. Mr. Earle B. Phelps, late professor of chemistry in the Hygienic Laboratory, served, throughout the period of study, as consultant, in active touch with all phases of the work, and had a large share in developing its general plan and much of its detail. We

are indebted to him for most generous assistance in all stages of the work including its planning, execution and interpretation.

For the hydrometric work, which forms an essential part of the study, the Director of the United States Geological Survey, on request of the Surgeon General, assigned an expert hydrographer, Division Engineer C. E. Ellsworth, with Assistant Engineer R. M. Adams, United States Geological Survey, to supervise the collection and compilation of data. A very considerable part of the hydrometric data used were collected and compiled by Messrs. Ellsworth and Adams, and the remainder of the work was done more or less directly under the advice of Mr. Ellsworth. Acknowledgment is accordingly made to the Director of the Geological Survey for providing this assistance, and to Mr. Ellsworth and Mr. Adams personally for their services.

To Dr. Lowell J. Reed, associate professor of biometry and vital statistics, the Johns Hopkins University, school of hygiene and public health, and consultant in statistics to the Public Health Service, acknowledgment is made for advice and assistance in the statistical analysis of some of the bacteriological data presented in Section VI.

Finally, we wish to acknowledge the courtesies shown and assistance rendered by the district engineer officers, United States Army Engineer Corps, in charge of the district offices at Cincinnati, Pittsburgh, Louisville, and Wheeling, and to members of their staffs, in giving access to their maps and other records, and by the health authorities of all the States having territory within the watershed in furnishing data from their records.

Personnel of Ohio River Investigation, July, 1913, to December, 1916

[Official designations are as of December, 1916]

Passed Asst. Surg. W. H. FROST, in charge

MEDICAL OFFICERS

Passed Asst. Surg. PAUL PREBLE [1] (October, 1914– —).
Passed Asst. Surg. L. R. THOMPSON [1] (October, 1913– —).
Asst. Surg. M. H. NEILL (July, 1913–October, 1914).
Asst. Surg. LISTON PAINE (April, 1914–October, 1914).
Asst. Surg. JOSEPH BOLTEN (April, 1915– —).
Asst. Surg. H. F. SMITH [1] (April, 1915– —).
Epidemiologist ALLEN W. FREEMAN [1] (November, 1915– —).

SANITARY ENGINEERS

Sanitary Engineer R. E. TARBETT [1] (July, 1913– —).
Sanitary Engineer J. K. HOSKINS [1] (December, 1913– —).
Sanitary Engineer H. W. STREETER (February, 1914– —).
Sanitary Chemist J. A. CRAVEN (May, 1915–January, 1916).
Sanitary Engineer W. G. STROMQUIST [1] (May, 1916– —).

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Special Expert W. C. PURDY (June, 1914– —).

BACTERIOLOGISTS

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Sanitary Bacteriologist J. W. MCBURNEY (November, 1913–November, 1914).
Sanitary Bacteriologist H. B. CORBITT (November, 1913–October, 1914).
Sanitary Bacteriologist E. E. SMITH, 2d [1] (March, 1914– —).
Sanitary Bacteriologist H. M. CAMPBELL (March, 1914– —).
Sanitary Bacteriologist M. V. VELDEE (March, 1914–October, 1915).
Sanitary Bacteriologist A. M. BESEMER (March, 1914–October, 1914).
Sanitary Bacteriologist C. M. SHERWOOD (April, 1914–November, 1914).
Sanitary Bacteriologist MAX LEVINE (May, 1914–August, 1914).
Sanitary Bacteriologist C. T. BUTTERFIELD (August, 1915– —).
Sanitary Bacteriologist E. J. THERIAULT [1] (May, 1915– —).

ADMINISTRATIVE ASSISTANT

Pharmacist F. A. SOUTHARD (July, 1913– —).

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[1] Assigned during a part of the indicated period to other studies, following the Ohio River investigation.

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INTRODUCTION *

W. H. Frost

By act of Congress of August 14, 1912, the scope of the Public Health Service was extended to include, among other added duties, that of studying "sanitation and sewage, including the pollution, either directly or indirectly, of the navigable streams and lakes of the United States"; and one of the first investigations to be taken up in compliance with this provision was a study of the pollution of the Ohio River.

The Ohio was selected for special study not as an isolated and local problem, but rather as a type of the large inland rivers which are a characteristic feature in the geography of the United States, and which present the most complex and difficult of the country's problems in the control of sewage pollution. The purposes of the study have, therefore, been to collect such data as would serve:

(1) To give a quantitative statement of the pollution of the river in important zones, as existing at the time of the study, with such evaluation as possible of the relative importance of individual sources or units in contributing to this pollution, and of the relation of the conditions to the public health.

(2) To furnish the basis for estimating with reasonable precision the changes in status of pollution which may be expected in the future to result from a given change in one or more of the factors concerned; as, for example, from a given increase in the various units of population, or from a given reduction in the polluting effect of their sewage by artificial treatment; or from changes in the velocity of flow, due to the construction of additional dams, as now projected, for improvement of navigation.

(3) To investigate the possibility of establishing definite quantitative relations between the intensity of pollution, as measured by various laboratory tests, and such obvious factors as are readily determinable by field surveys. Especially has it been the purpose, in this connection, to make a quantitative study of natural purification as related to time of flow, temperature, and other determinable factors of presumptive importance.

With these purposes in view, the study has been carried out in much more detail than would have been required for the single purpose of arriving at an estimate of immediately existent conditions

* Manuscript submitted for publication March, 1924

and their present relation to public health; and the data collected are presented here with reference to their future and general rather than their immediate and local significance. As to the more general purposes, they have been pursued in the hope rather than in the expectation of accomplishment, not in full but in sufficient measure to be useful. The factors concerned in the pollution and especially, perhaps, in the self-purification of a great river system are of extreme complexity; and in so far as they may be found to be related in any general and simple way this is to be considered as a fortunate rather than an anticipated circumstance. The study has, therefore, been to a considerable extent experimental, designed to test the applicability of the methods applied to the ends in view.

GENERAL STATUS OF POLLUTION IN THE OHIO RIVER

The Ohio is one of the principal tributaries of the Mississippi River, and among the largest river systems of the United States. Conditions with respect to sewage pollution are essentially the same as those existing quite generally in the large inland streams of the country, except that the necessity for some measure of control appears to be rather more imminent than in any other stream of equal size.

The main stream, measured from its junction with the Mississippi to the confluence of the Allegheny and Monongahela at Pittsburgh, is 960 miles in length; and from Pittsburgh to the headwaters of the Allegheny is a further distance of about 400 miles. The river drains an area of 203,000 square miles, with a population of 14,500,000, or about 71 inhabitants per square mile. Of this population approximately 5,100,000 reside in cities of more than 2,500 inhabitants. Directly upon the main stream are cities and villages aggregating 2,400,000 in population, the largest units in this aggregate being the metropolitan districts of Pittsburgh (1,043,000) at the upper end; Cincinnati (564,000) midway between Pittsburgh and the mouth; and Louisville (286,000) 130 miles below Cincinnati.

All the cities upon the watershed necessarily discharge their sewage into the river, either directly or through its tributaries. Except near the periphery of the watershed, where the streams are small, the immediate pollution resulting from the discharge of sewage is seldom grossly offensive, owing to the rather ample dilution. Consequently the artificial treatment of sewage is almost negligible, entirely so along the main stream. The distances between cities are, moreover, generally so great that natural purification greatly reduces the pollution; and if it were required merely to prevent gross pollution, offensive to the senses of sight and smell, the necessity for any general control of sewage pollution would be rather

distant, and would present itself eventually as a series of local necessities to be dealt with individually.

However, all the large cities and a number of the smaller communities situated upon the Ohio take their water supplies from the river; and in the case of the large cities it is at least questionable whether any other sources of supply are available. Therefore, it becomes necessary to consider the sewage pollution of the river from the standpoint of its effect upon these water supplies, protection of which must apparently be the paramount consideration in the eventual control of the pollution.

That the Ohio River is sufficiently polluted throughout its course to be dangerous has been only too well proved by the experience of every community which has taken its water supply direct from the river without purification. It is, moreover, generally conceded that even though urban sewage were entirely excluded, the waters of the river would still be unfit for public use without artificial purification, due to their characteristic turbidity and to inevitable contamination from surface drainage. Thus, an efficient plant for the artificial purification of its water is a necessary part of the equipment of every community which draws its supply from the river at any point; and the objective in control of sewage pollution should evidently be to limit the burden placed upon these plants, allowing them an ample margin of safety, without unduly increasing their cost of construction and operation.

It would appear, from evidence presented later in this report, that the best types of filtration plants, efficiently operated with supplementary chlorination, were still able, during the period of this study, to deliver water supplies of good quality; and that in recent years their quality has improved rather than deteriorated, indicating that improvements in water purification processes have counterbalanced the increased pollution of the sources of supply due to growth of urban population and extension of sewerage. Nevertheless, it can not be anticipated that this favorable balance can be indefinitely maintained. The rate of increase in sewered population is such that, unless some altogether unexpected advance is made in the efficiency of water purification processes, the time must come when purification plants will be overtaxed by the steadily increasing sewage pollution. To meet this condition, or rather to prevent it, the pollution of the river must be restricted within certain limits, compatible with its use as a source of water supply; and this requires the artificial purification of sewage before its discharge. It need not be doubted that this can be accomplished, and that it will be when the necessity becomes sufficiently obvious. It is important, however, not only that the measures be effective and that they anticipate any public injury, but also that they accomplish the result at a minimum of

cost, and it is this latter consideration especially which requires that any measures adopted be based upon accurate knowledge of the factors concerned.

FACTORS CONCERNED IN THE POLLUTION OF THE RIVER

The first step in devising a specific administrative plan of control is the formulation of some standard, defining the limits of permissible pollution in the river water as it enters the intake of a purification plant. This standard will presumably be stated in terms of quantitative bacteriological tests, and will be such that a purification plant of the best practicable design will be able at all times to deliver from the raw water an effluent of unquestioned safety. It need not be a uniform standard in all zones where it is to be applied; but may well take into account various considerations affecting the nature and efficiency of purification processes. Also, any standards adopted may be modified from time to time, as processes of water purification are either improved or found, by experience, to be less reliable than supposed. But, while the adoption of some definite standard or set of standards is necessary as the basis for a plan of administrative control of pollution, it is not requisite for the purposes of the present study to have any specific standards in view, but only to recognize that such standards as may eventually be adopted must refer to the river in zones from which water supplies are taken, and that the permissible limits must be far short of such gross pollution as is frequently encountered in the zones immediately below the sewer outfalls of the larger cities. Then as a preliminary to devising specific measures which will have the effect of controlling the pollution in these zones within such limits as may be adopted, it is necessary to have a quantitative analysis of the factors concerned in the pollution, with special reference to the part which each controllable unit plays.

The river at any point is subject to contamination from all the wastes, of whatever character, which may find their way into the stream above this point. The wastes brought into the stream by natural drainage are not subject to control in any considerable degree, and while they are by no means harmless, they are not likely, by themselves, to be in sufficient concentration to give rise to pollution beyond the limits which may be considered permissible. The wastes discharged as sewage; that is, through artificial drainage systems especially designed to carry off domestic and industrial wastes, are of more importance from the standpoint of control, because they are more concentrated and generally more offensive in character, and because they may, if necessary, be collected and more or less completely purified by artificial treatment before their discharge. Consequently, it is of special importance to ascertain the

proportionate part which sewage, as contrasted with natural drainage, plays in the status of pollution; also to ascertain, if possible, the share contributed by each one of the many sewered communities on the watershed, which constitute units in any system of control.

In a general way, and with due allowance for differences in the character and magnitude of waste-producing industries, it may be assumed that the wastes discharged from a series of sewered communities are proportionate to their respective populations. The immediate pollution contributed by any sewered community would, then, be proportionate to the population of the community and the volume of the stream into which its sewage is discharged, as this determines the dilution or concentration of the sewage constituents. The effect at any point more or less distant downstream is, however, modified by the direction and extent of any changes which may have taken place in the mixture of sewage and river water. It has long been known that these changes are in the direction of purification, as evidenced chiefly by the oxidation of unstable and putrescible organic matter into stable, nonputrescible compounds, and by a diminution in numbers of sewage bacteria. It is known, too, that these changes are to a large extent the result of biochemical reactions, which proceed more or less slowly, so that, other conditions being equal, their extent is related to time, and this, in a stream, is a function of distance and velocity of flow.

Thus, with reference to a given section of a river, two communities discharging equal amounts of identical wastes but situated at different distances upstream are of unequal importance relative to the pollution at this section, due to differences in the extent of natural purification intervening. Should it become necessary to reduce the sewage pollution at the downstream section, it is a question, both of justice and of economics, whether the restrictions imposed as to sewage treatment should be the same for both these communities, or proportionate to their respective shares in the effect, or limited, at first, to the nearer community, which is the greater offender. The principle to be applied in distributing the burden of prevention is a matter to be decided by judicial and administrative authorities; but, whatever the principle may be, its application requires some quantitative knowledge of the effect which each unit of sewage discharge has upon the pollution at a given point or points downstream.

The greatest difficulty in such an analysis lies in the fact that we have as yet no exact knowledge of the laws governing natural purification. It is known, in a general way, that it is a factor of great importance. For example, evidence presented in the suit of Missouri *v.* Illinois [1] showed that pollution attributable to the sewage

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[1] Leighton, M. O., Pollution of Illinois and Mississippi Rivers by Chicago Sewage. A digest of the testimony taken in the case of the State of Missouri *v.* The State of Illinois and the Sanitary District of Chicago, U. S. Geological Survey, Water Supply and Irrigation Paper No. 194, Washington, 1907.

of the Chicago Sanitary District, discharged through the Chicago Drainage Canal and the DePlaines River into the Illinois River, was hardly demonstrable at the mouth of the Illinois River, some 300 miles downstream, and though the factors concerned were not fully analyzed, it is obvious that this effect was attributable only in small part to physical dilution, and must be credited chiefly to natural biological processes. From this it might safely be inferred that in a river of such great length as the Ohio, natural purification would be a preponderating influence in determining the relative importance of upstream communities as factors in the pollution at points far downstream. Consequently, it has been the chief purpose of this study to acquire some definite and quantitative, even though entirely empirical knowledge of this all-important factor of natural purification; to relate it, if possible, to such simple and readily determinate variables as time of flow, temperature, and season. It may, however, be repeated that the investigation was undertaken with no assurance that fulfillment of this purpose was possible.

PLAN AND DEVELOPMENT OF LABORATORY AND FIELD STUDIES

The study of the Ohio River was begun in July, 1913, with the assignment of the officer in charge, a junior medical officer, a sanitary engineer, and a pharmacist as administrative assistant. On account of its central location Cincinnati was selected as headquarters, and while a central laboratory was being equipped there a preliminary survey of the river was made, plans were laid for the establishment of branch laboratories, and the necessary personnel were assembled. The Cincinnati laboratory was put into operation in November, 1913, and until January 1, 1914, was engaged in preliminary investigations and in testing and standardizing methods of collecting and examining samples.

In the meantime subsidiary laboratories were established at Pittsburgh, at the upper end of the river; Portsmouth, Ohio, about 350 miles below Pittsburgh and 120 miles above Cincinnati; and at Louisville, Ky., about 130 miles below Cincinnati (600 miles below Pittsburgh), and systematic work was begun at these three substations and at Cincinnati early in January, 1914. In April, 1914, two additional laboratories were added, namely, one at Wheeling, W. Va., 100 miles below Pittsburgh, and one at Paducah, Ky., near the mouth of the river.

At each of these laboratories samples for chemical and bacteriological examinations were collected from the river and its tributaries at regular intervals, usually three or six times weekly, from fixed sampling stations, within such distance as to be accessible by motor

boat or other conveyance. This schedule of work was continued until October 15, 1914, when the laboratories at Pittsburgh, Wheeling, Portsmouth, and Paducah were discontinued, limiting the studies thereafter to the laboratories at Cincinnati and Louisville, examining samples from the river and its tributaries in the vicinity of and between these two cities. The study of this portion of the river was continued, without interruption, until December 31, 1916, giving three full years of observation.

The purpose of the laboratory studies was to ascertain, as precisely as possible, the character and extent of pollution at a series of river sections under a wide range of seasonal and hydrographic conditions, with special reference to changes in pollution resulting from the discharge of sewage from large cities, the inflow of major tributaries, and the influence of natural agencies of purification in stretches suitable for observing this effect. The plan of laboratory studies, the considerations governing the selection of sampling stations, and the details of procedure followed are discussed in Section IV, hereafter.

While this work was in progress, steps were being taken to collect the other data necessary for correlation with the results of laboratory tests. Necessary data relative to the areas and populations of the natural subdivisions of the Ohio watershed were compiled from available sources. Under the direction of an expert hydrographer, assigned from the United States Geological Survey, the data required for computing stream flow were assembled from scattered sources and supplemented by additional measurements made at existing or newly established gaging stations. From these records, taken together with contour maps of the river bed, available from the District Engineer Offices of the United States Army Engineer Corps, computations were made of the velocities and times of flow in successive river prisms under observed conditions of flow. Also, during the summers of 1914 and 1915, field parties, each consisting of a medical officer and a sanitary engineer, made a detailed sanitary survey of the watershed, collecting information as to sewerage; the character and magnitude of waste-producing industries; the sources, treatment, and quality of municipal water supplies; other sanitary conditions presumably affecting the prevalence of typhoid fever, and detailed records of the prevalence of this disease in the five years 1910–1914. In the course of this survey visits were made to all incorporated communities of more than 8,000 inhabitants upon the entire watershed, and all communities of whatever size situated directly upon the Ohio River, and the information thus secured was supplemented by data from the records of the health authorities of the several States.

PRESENTATION OF DATA

The data collected in these several lines of inquiry are presented in this report in six sections, dealing respectively with:

(1) The physiography of the watershed in general.

(2) Measurements of discharge and velocity in the main stream.

(3) Sources of pollution, with special reference to urban sewage, both domestic and industrial.

(4) The general plan of laboratory studies in relation to the other data collected.

(5) The results of chemical analyses of samples from the Ohio and its tributaries.

(6) The results and significance of bacteriological examinations.

An additional section, dealing with studies of the plankton and related organisms [2] has already been published separately.

The results of sanitary surveys of communities upon the watershed, with reference to the prevalence of typhoid fever and its relation to their water supplies are not included in this report, as they are not believed to be essential to its main purpose. In so far as they are of general interest, they will be presented separately in a subsequent report, and, as regards their immediate and local interest, they have already been made available to the health authorities of the States concerned.

All other data collected in the several lines of inquiry above indicated are included in this report,[3] but only in such detail as is necessary to relate them to each other in a general view of the factors fundamentally concerned in the pollution of the main stream. The more detailed data which have necessarily been collected and used in compiling the rather broad summaries here given are not only too voluminous for publication, but are also, for the most part, of less general interest, limited largely to such authorities or technical experts as may have occasion to apply them in subsequent investigation. In order that they may be available for such purposes, they are kept permanently on file at Cincinnati, where they are accessible to officials and other interested persons, upon application to the Surgeon General.

[2] W. C. Purdy, A Study of the Pollution and Natural Purification of the Ohio River, I., The Plankton and Related Organisms, U. S. Public Health Service, Public Health Bulletin No. 131, Washington, 1923.

[3] A separate report on studies of dissolved oxygen is made in Public Health Bulletin No. 146.

Section I

PHYSIOGRAPHY

By J. K. Hoskins

The Ohio River is formed at Pittsburgh, Pa., by the junction of the Allegheny and Monongahela Rivers. From this origin it flows in a general southwesterly direction, discharging into the Mississippi at Cairo, Ill., a distance of 968 miles by water from Pittsburgh. For the first 40 miles its course is through Pennsylvania, but from the western border of Pennsylvania to its mouth the river forms an interstate boundary, separating Ohio, Indiana, and Illinois on the north from West Virginia and Kentucky on the south.

The basin of the Ohio, as shown in Figure 1, lies in the east central portion of the United States, extending from latitude 34° 10′ to 42° 30′ north, and from longitude 78° 00′ to 89° 20′ west. Its boundaries approach within a few miles of Lake Erie on the north, pass through northern Georgia and Alabama on the south, and extend from the Appalachian ridge on the east, westward to the Mississippi River. Portions of 14 States lie within the basin, including large areas of the States of Pennsylvania, Ohio, Indiana, Illinois, West Virginia, Kentucky, and Tennessee, with smaller areas of New York, Maryland, Virginia, North Carolina, Georgia, Alabama, and Mississippi. The total area of the watershed is approximately 203,000 square miles, which is about 7 per cent of the area of the continental United States; is about equal to the combined areas of the New England and Middle Atlantic States, Maryland, and one-half of Virginia; and is nearly equal to the area of France as constituted in 1914. The distribution of this area in the 14 States which contribute to it is shown in Table No 1.

Table No. 1.—*Relation of States to the Ohio River Basin*

State	Total area of State	Area in Ohio Basin	State area in basin	Basin area in State
	Sq. miles	*Sq. miles*	*Per cent*	*Per cent*
New York	49, 204	1, 942	3. 95	0. 96
Pennsylvania	45, 126	15, 528	34. 41	7. 66
Maryland	12, 327	430	3. 49	. 21
Virginia	42, 627	7, 130	16. 72	3. 52
North Carolina	52, 426	6, 226	11. 87	3. 07
Ohio	41, 040	29, 499	71. 88	14. 55
West Virginia	24, 170	20, 394	84. 37	10. 06
Kentucky	40, 598	39, 144	96. 41	19. 31
Tennessee	42, 022	33, 447	79. 59	16. 50
Georgia	59, 265	1, 470	2. 48	. 73
Alabama	51, 998	6, 763	13. 01	3. 34
Mississippi	46, 865	379	. 81	. 19
Indiana	36, 354	28, 962	79. 66	14. 29
Illinois	56, 665	11, 377	20. 07	5. 61
Total	600, 687	202, 691	33. 74	100. 00

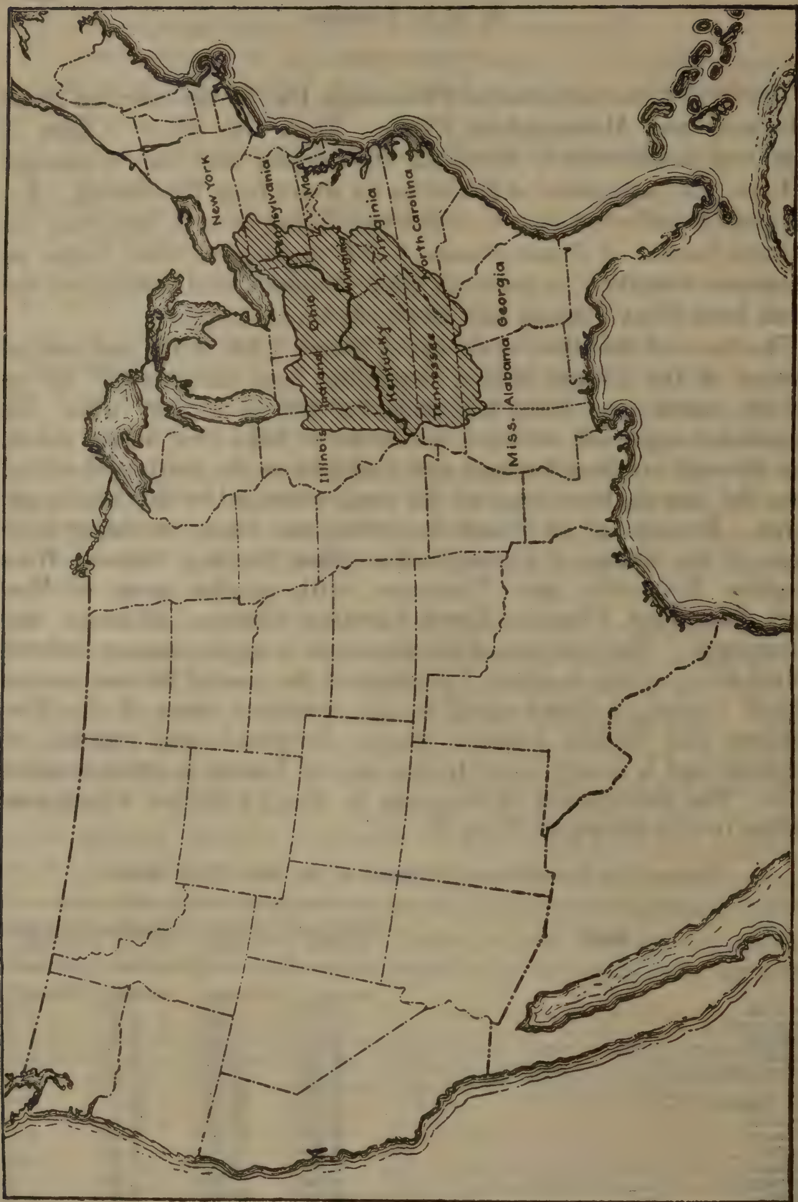

FIG. 1.—Watershed of the Ohio River in relation to the United States

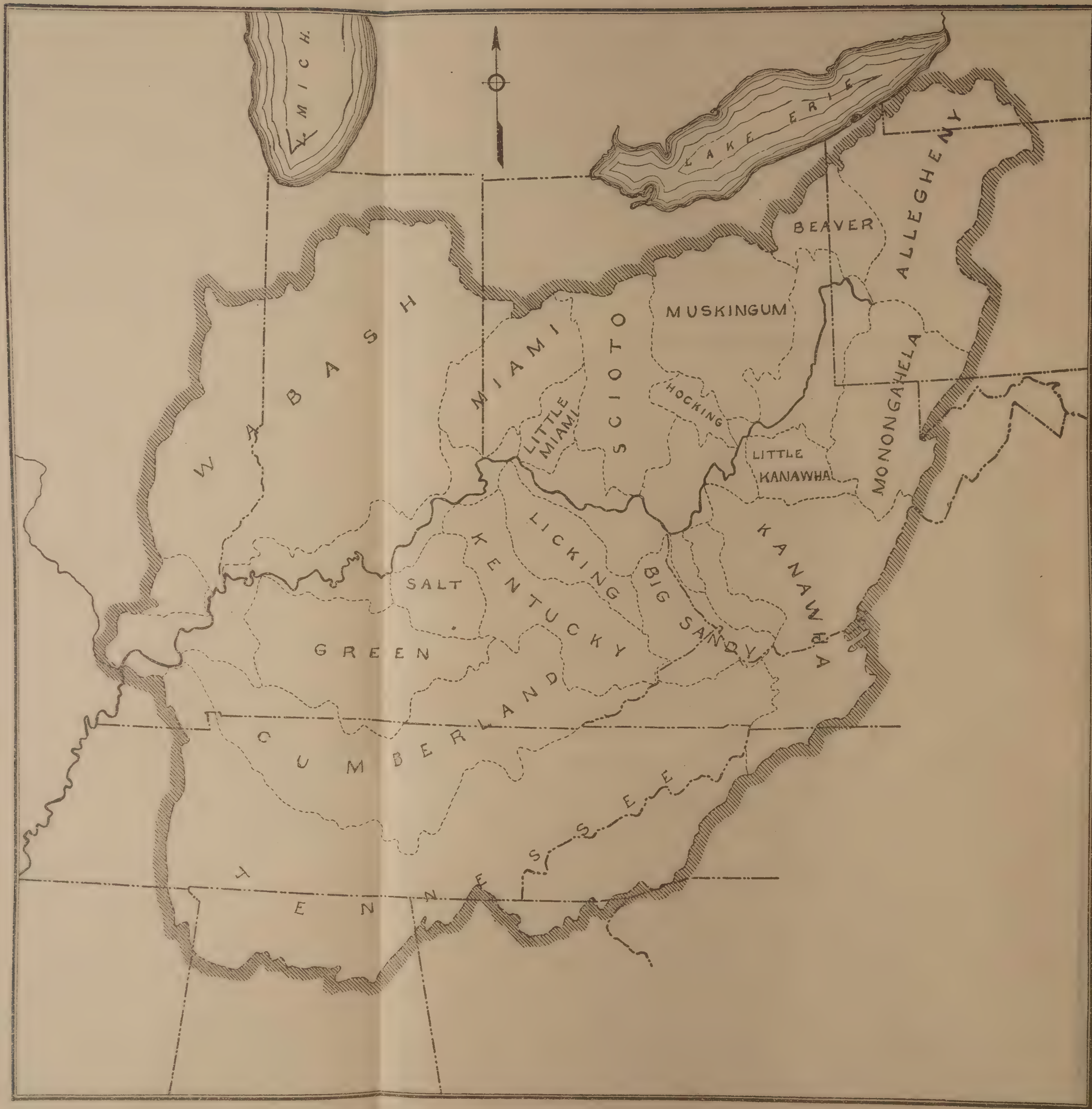

Fig. 2.—Map of the Ohio River watershed, showing boundaries of principal tributary drainage areas

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TRIBUTARY DRAINAGE AREAS

The principal tributaries of the Ohio are those listed in Table No. 2, which, together with Figure 2, shows their points of junction with the main stream and the size and location of their drainage areas.

TABLE No. 2.—*Junctions and drainage areas of the principal tributaries of the Ohio River*

Tributary enters from the—		Distance from Pittsburgh to tributary mouth	Drainage area	
North	South		(1)	(2)
		Miles	*Sq. miles*	*Sq. miles*
Allegheny		0	11,677	11,680
	Monongahela	0	7,333	7,339
	Chartiers Creek	3	270	
Beaver		25	3,148	3,140
Little Beaver		39	528	
	Wheeling Creek, W. Va	90	301	
	Middle Creek	154	557	
Muskingum		172	7,989	8,083
	Little Kanawha	184	2,281	2,339
Hocking		199	1,227	
	Kanawha	265	12,073	12,200
Raccoon Creek		275	663	
	Guyandotte	305	1,659	
	Twelve Pole Creek	313	447	
	Big Sandy	317	4,219	4,265
	Little Sandy	336	755	
Scioto		356	6,529	6,410
Little Miami		463	1,782	1,714
	Licking	469	3,651	3,636
Mill Creek		471	162	
Miami		489	5,396	5,410
	Kentucky	543	7,059	6,912
	Salt	627	2,851	
Blue		660	495	
	Green	779	9,154	
Wabash		840	32,476	32,890
Saline		858	1,164	
	Treadwater	864	947	
	Cumberland	910	17,936	17,860
	Tennessee	922	40,608	40,740
Small tributaries			17,354	
Total of Ohio water shed			202,691	203,900

[1] Areas by planimeter measurements from Post Route Maps, 1913.
[2] From data of United States Geological Survey. (These figures used in hydrometric computations of Section II.)

As no complete topographic survey of the whole basin of the Ohio River has been made, the boundaries and areas of the basin and its component parts have not yet been defined with great precision. The areas given in column (1) of Table No. 2 are computed by planimeter measurements of watersheds traced on United States post route maps by interpolation between the tributaries shown, and corrected by reference to United States Geological Survey topographic maps in regions for which these are available (about one-third of the total basin area). The areas given in column (2) of the same table are from records of the United States Geological Survey and are used in this report for hydrometric computations upon all the subdivisions for which they are available. While the areas as given in these two columns do not agree precisely, the difference

in the total for the basin is less than 0.6 per cent, and for tributary watersheds the maximum difference is 4 per cent—in most cases less than 2 per cent. The drainage areas above certain points on the main stream, as given in Table No. 3, are from the same data as are used in column (2) of Table No. 2.

TABLE NO. 3.—*Drainage areas of Ohio River above certain points*

Point	Area[1] above	Point	Area[1] above
	Sq. miles		*Sq. miles*
Pittsburgh, Pa.	19,020	Above Scioto River	62,320
Above Beaver River	19,630	Portsmouth, Ohio (includes Scioto River)	68,730
Davis Island Dam, Pa.	19,310	Above Little Miami River	70,950
Below Beaver River	22,670	Cincinnati, Ohio (includes Licking River)	76,320
Beaver Dam, Pa. (Dam No. 6)	22,690	Above Miami River	76,580
East Liverpool, Ohio	23,440	Above Kentucky River	83,130
Wheeling, W. Va. (includes both Wheeling Creeks)	24,980	Louisville, Ky.	91,190
Above Muskingum River	27,480	Above Green River	98,000
Marietta, Ohio (includes Muskingum River)	35,560	Evansville, Ind.	107,100
Parkersburg, W. Va. (includes Little Kanawha River)	37,950	Above Wabash River	107,700
Point Pleasant, W. Va. (includes Kanawha River)	52,690	Above Cumberland River	144,000
Catlettsburg, Ky. (includes Big Sandy River)	60,570	Paducah, Ky. (includes Tennessee River)	202,700
		Cairo, Ill. (total drainage area)	203,900

NOTE.—Areas determined and supplied by the United States Geological Survey.

[1] Four significant figures are given in this table, but only three significant figures used in body of report. Intermediate areas determined by subtraction of values given in this table are liable to error, which may be as great as 100 square miles.

GEOLOGY

The main geologic subdivisions of the Ohio Basin are shown diagrammatically in Figure 3, compiled from various data, chiefly from Le Conte's Geologic Map of the Eastern United States [1] and from State geologic maps. Limestone and shale are the most common bedrocks. The most extensive formations are the Carboniferous, which extends through the eastern and southeastern portion of the basin; the sub-Carboniferous in the central portion, and the Cambrian and Silurian, which cover large areas of the north-central and southeastern portions of the basin. The northern part of the watershed, above a line which reaches as far south as Cincinnati, is overlaid with glacial drift, which forms the extraordinarily deep and fertile soil of the prairies in the western part of the basin. In the mountain region of the Appalachians the soil is light and sandy, and in the level areas of the Mississippi plains it is alluvial, consisting of a rich loam mixed with clay.

The mineral deposits of greatest economic and industrial importance are coal, iron ores, petroleum, and natural gas. The most extensive coal measures are those comprised in the Appalachian fields, extending from western New York southwest to Alabama, and the Eastern Inte-

[1] Le Conte, Jos., Elements of Geology, Fourth Edition, p. 302.

FIG. 3.—Diagrammatic geological map of the Ohio River watershed. Compiled from various State geological maps, maps of the United States Geological Survey, and geological map of the eastern United States from Le Conte's "Elements of Geology," 1901, p. 302

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rior fields, lying in Illinois, southwestern Indiana, and western Kentucky. The greater part of the former and about half of the latter fields lie within the boundaries of the Ohio Basin which, in 1909, produced approximately 70 per cent of the bituminous coal mined in the United States.

The close association of iron ores with coal measures in the Appalachian fields, especially in western Pennsylvania, resulted in the early development of the iron and steel industries in that region. In recent years the ores smelted in this district have been largely drawn from the Lake Superior region; but the Pittsburgh district has maintained its early established supremacy as the principal center of production of iron and steel in the United States.

The principal supplies of petroleum and natural gas are found in the Appalachian fields of New York, Pennsylvania, Ohio, West Virginia, Kentucky, and Tennessee; the Lima-Indiana fields in southwestern Ohio and eastern and southern Indiana, and the Illinois fields in the central and southern parts of the State. The oil fields of the Appalachian region were the first to be developed in the United States, and in the early days of the industry were the principal source of supply. In recent years, due to decreased production in these areas, and to the opening up of new fields in other parts of the country, the oil fields of the Ohio Basin have furnished proportionately less of the total product of the United States. In 1909 the Appalachian fields of Pennsylvania, Ohio, and West Virginia still produced more than half of the natural gas used in the United States.

TOPOGRAPHY

The eastern and southeastern sections of the watershed, lying in the Appalachian region are mountainous, with steep quick-spilling slopes. West and north of this mountainous area is the more gently rolling country of southeastern Ohio, central Kentucky, and Tennessee, lying around the center of the basin, while the western and northwestern portions of the basin, including western Ohio, Indiana, Illinois, western Kentucky, and western Tennessee, are level, forming a part of the great central prairies of the Mississippi Valley. The streams entering the Ohio from the south flow usually in long narrow valleys, converging gradually toward the main stream or even, as in the case of the Cumberland and Tennessee Rivers, flowing a long distance practically parallel to the Ohio. Steep slopes at their headwaters render these streams subject to sudden changes in volume. The tributaries entering from the north, passing through more level country, flow in a general direction more nearly at right angles to the Ohio, but are quite tortuous. They are somewhat less flashy than the tributaries from the east and south.

FORESTATION

Originally about 50 per cent of the Ohio watershed was covered with forests, including practically the whole of the drainage area above Pittsburgh; but with agricultural and industrial development the forested areas have been reduced to something less than half their original extent. The wooded lands remaining at present, excepting small woodlots, lie mostly above the 1,500-foot contour, chiefly in the eastern and southeastern sections of the basin, in the Appalachian regions of Pennsylvania, West Virginia, Virginia, North Carolina, Kentucky, and Tennessee.

CHARACTER OF SURFACE AND GROUND WATERS

The waters of the main stream of the Ohio and of its tributaries throughout the greater part of the basin are characteristically turbid, so that for domestic and many industrial uses they require clarification by sedimentation and chemical precipitation, and are more satisfactorily treated by the so-called rapid-sand filtration than by the slow-sand process of filtration. In general, the streams from the western portion of the watershed are more turbid than those from the eastern section, the result of which is an increasing turbidity of the main stream from source to mouth. The waters from different parts of the watershed vary widely in the amount and character of mineral salts in solution; but they are, in general, of moderate hardness, ranging from 25 to 200 parts per million of total hardness in terms of $CaCO_3$. Streams which drain coal-mining sections, notably the Monongahela, are rather highly impregnated with acid iron salts, and even with free sulphuric acid, which materially affect the chemical composition and biology of the upper Ohio.

There is a wide range of variation between different sections of the basin with respect to the availability and quality of ground waters, of which no complete survey has been made. In the northern and western portions of the watershed ground waters of fairly acceptable quality are commonly available in sufficient quantities for supplying cities of moderate size. In the mountainous regions, where ground-water storage is reduced, supplies from underground sources are less frequently available; and in certain areas, especially in the coal fields, ground waters, where available in sufficient quantity, are often so highly mineralized as to be unfit for domestic and certain industrial uses. In some parts of Kentucky and Tennessee, underground streams are found in the cavernous limestone bedrock; but these may be considered as surface waters flowing in underground channels, rather than ground waters in the usual sense.

A detailed investigation of the public water supplies used by 176 municipalities located in the Ohio Basin with an aggregate popula-

tion of 4,640,000 which was made in 1914 and 1915 showed that 72 per cent of this population used surface waters; 6 per cent used water from subsurface sources, such as cribs and wells located in river beds; 8 per cent used mixed supplies from surface and underground sources; and only 14 per cent were supplied exclusively with ground water from wells and springs. The surface supplies were taken largely from open streams, only 4 per cent of the population being supplied with water which had been stored in impounding reservoirs. Of the cities situated directly upon the Ohio River all those of more than 18,000 inhabitants, and several of smaller size, depend upon the river for their source of supply. The total population of Ohio River cities thus supplied, including Pittsburgh, which derives its supply from the Allegheny, exceeds 1,700,000.

CHARACTERISTICS OF OHIO RIVER CHANNEL

The Ohio is largely an alluvial stream in a fairly advanced stage of channel adjustment, as is evidenced by the fact that the velocities of flow are quite uniform throughout the length of the channel, and also by the fact that the meanders of the line of flow are gradual and wide-sweeping. The stiff clay soil has, however, brought about an adjustment to high rather than to low discharges, resulting in a channel floor that is relatively wide and flat. This condition causes wide variations in the velocity of flow between high and low river stages.

The river bed in the upper reaches consists of coarse gravel and boulders, but in passing downstream these are gradually replaced by sand and silt deposits, which sift constantly under varying flow conditions. The channel is made up of a series of pools and riffles, alternating with stretches of rather smooth, uniform grade. The depth of water in the pools at low stages ranges from less than 10 feet to over 50 feet, while in the riffles, especially in the upper part of the river, the depths are frequently less than 3 feet at low-water stages.

The slope of the river, as measured by the elevation of the water surface, decreases gradually from 11.4 inches per mile between Pittsburgh and Wheeling to 3.7 inches per mile in the last 70 miles above its mouth. The only falls of any magnitude, which are at Louisville, are formed by an irregular mass of limestone lying across the bed of the river, causing a drop of 23.9 feet in a distance of 2.3 miles. These falls are not navigable excepting at high-water stages, and even then with danger and difficulty. For this reason the Louisville & Portland Canal was constructed in 1830 and has since been in use to accommodate river traffic around the falls.

From Pittsburgh to Cincinnati, the channel is narrow and comparatively uniform in width, ranging from 1,200 feet to 1,500 feet at low water. In the long pool between Cincinnati and Louisville the channel widens considerably, contracting again below the falls, and then gradually widens, reaching an ultimate width of over a mile at the mouth. Eighty permanent islands, ranging in area from 1 to 5,000 acres, are scattered throughout the channel length, about 50 of these being above Louisville. Many of these islands are under cultivation.

NAVIGATION AND IMPROVEMENT

The Ohio River was formerly almost wholly closed to navigation during ordinary low-water stages, because of the shallow depth of water over numerous riffles. Efforts have been made to overcome this handicap by the use of shallow-draft vessels, but the limitations of size of such boats are such that, in order to maintain navigability throughout the year, extensive channel improvements, not yet completed, have been in progress under the Federal Government for nearly 100 years. A detailed history of this work may be found in the "Report of an Examination of the Ohio River [2]" prepared by a board of U. S. Army Engineers.

The first work undertaken by the Federal Government was in the nature of temporary improvement by the removal of sand bars and snags from the channel. Later, permanent construction was authorized, including the erection of dikes and cut-off dams; and more recently, since about 1875, the main program of improvement has been the construction of a series of removable dams, designed to maintain a navigable depth at low-river stages. The complete project, which has been finally adopted and is now being developed, contemplates a series of 54 dams and locks which will maintain a minimum navigable depth of 9 feet at low water throughout the length of the river. The dams consist of permanent sills and Chanoine wickets which may be raised and lowered as required. In river stages sufficiently high for navigation in open channel the wickets are lowered and vessels pass over the sills of the dams. In low stages, when the channel depth becomes less than about 9 feet, the wickets are raised, forming a pool, and vessels pass around the dam through a lock.

Table No. 4 shows the location and status of such of these dams as were completed or under construction at the close of the calendar year 1915. At that time 17 of the dams had been completed and 17 were under construction.

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[2] H. Doc. No. 492, 60th Cong., 1st sess., Government Printing Office, Washington, D. C., 1908.

TABLE No. 4.—*Location and status of movable dams on Ohio River completed and under construction at end of year 1915*

Dam No	Distance by water from Pittsburgh	Status at end of 1915	Approximate length of backwater pool formed [1]	Elevation of upper pool [2]
	Miles		*Miles*	*Feet*
1	4.7	Completed	4.7	703.0
2	9.0	do	4.3	699.9
3	10.9	do	1.9	692.1
4	18.6	do	7.7	684.4
5	23.9	do	5.3	676.8
6	28.8	do	4.9	668.3
7	36.9	do	8.1	662.6
8	46.1	do	9.2	655.7
9	55.6	do	9.5	649.3
10	65.7	do	10.1	641.9
11	76.3	do	10.6	633.5
12	87.0	Under construction	10.7	626.2
13	95.8	Completed	8.8	617.8
14	113.8	Under construction	18.0	610.5
15	128.9	do	15.1	602.2
16	146.4	do	17.5	594.4
17	167.4	do	21.0	586.6
18	179.3	Completed	11.9	578.4
19	191.4	Under construction	12.1	572.2
20	201.7	do	10.3	564.5
21	213.8	do	12.1	557.0
22	220.1	do	6.3	551.4
24	242.0	do	[1] 19.0	535.5
26	278.0	Completed	[1] 29.3	519.5
28	310.9	do	[1] 28.4	505.6
29	319.4	Under construction	8.5	498.5
31	358.4	do	[1] 34.0	483.0
33	404.0	do	[1] 30.3	468.0
35	449.7	do	45.7	455.4
37	481.3	Completed	[1] 28.9	441.1
39	529.6	Under construction	[1] 38.6	426.0
41	604.0	Completed	[1] 69.8	412.0
43	630.2	Under construction	[1] 46.0	383.0
48	804.1	do	41.9	338.0

[1] Values designated thus give actual pool lengths extending back to open channel extreme low-water profile, and do not take into account effects of intermediate future dams not listed in present table, which will when completed affect the upper ends of these pools for various distances, according to the location of these future dams. Values not designated thus give pool lengths extending back to next dam upstream either actually completed or under construction.

[2] Elevations are in terms of feet above mean sea level datum, Sandy Hook, N. J.

The completed dams suffice to maintain a 9-foot slackwater depth from Pittsburgh to Dam No. 11 (above Wheeling), a distance of 76 miles; from the upper limits of Cincinnati to Dam No. 37, a distance of about 20 miles, and from Madison, Ind., to Dam No. 41 at Louisville, a distance of 49 miles. Between these stretches, in sections of the river where dams are not in operation, the minimum depth of the stream may fall to 3 feet or less. Table No. 5 shows the number of days during the years 1911 to 1915, inclusive, that the wickets of each dam were raised.

TABLE No. 5.—*Summary of number of days Ohio River dams were raised, creating pool stages, during the five years, 1911–1915*

[Data furnished by district engineer offices, Pittsburgh, Wheeling, Cincinnati, and Louisville]

Dam No.	Number of days dam was raised					Dam No.	Number of days dam was raised				
	1911	1912	1913	1914	1915		1911	1912	1913	1914	1915
1	132	56	160	202	228	9	([1])	([1])	([1])	[2] 34	176
2	112	142	195	197	210	10	([1])	([1])	([1])	([1])	[2] 13
3	133	141	196	196	202	11	31	117	194	197	210
4	130	142	186	194	212	13	42	113	183	172	167
5	126	132	182	193	203	18	46	124	164	191	174
6	125	131	164	192	185	26	([1])	([1])	([1])	[2] 45	137
7	([1])	([1])	([1])	[2] 81	185	28	([1])	([1])	([1])	([1])	[2] 68
8	46	116	161	113	176	37	41	57	112	179	80

[1] Not completed. [2] First time raised.

In addition to their importance in maintenance of navigable stream depth, these dams have an important bearing upon the biology of the river, through the establishment of quiescent pools and the prolongation of the time of passage of water downstream. Those already completed have the effect of greatly prolonging the time of flow in the first 75 miles below Pittsburgh, and it is estimated that with all the dams in operation the time of flow from Pittsburgh to the mouth of the river at low stages will be from two to three times as great as before any of the dams were constructed. This increased time of flow is of very great importance in relation to natural processes of purification in the stream.

TEMPERATURE

Such an extensive and diversified area as the Ohio Basin necessarily presents a considerable range of climatic conditions. Mean monthly temperatures at 16 observation stations are summarized in Table No. 6. As the period of record is longer at some stations than at others the means given in this table are not entirely comparable; but they serve at least to illustrate usual ranges of seasonal variation and differences between different portions of the watershed. Throughout the area July is the month of highest mean temperature, ranging from 66.8° at Bolivar, N. Y. in the extreme northeast to slightly over 79° at several stations in the southern and western portion of the watershed. The widest ranges of difference in temperature are in the winter months. In the northern and northeastern sections of the basin the mean temperature is below the freezing point for two or three months, snowfalls remain upon the ground for considerable periods, and the streams are frequently covered with ice. In the southern sections of the watershed snow falls much less frequently, and when it falls, melts rapidly, while ice is seldom formed even upon the small streams. The main stream of the Ohio is very rarely frozen over, though ice is often brought down by the northern tributaries in sufficient quantity to interrupt navigation.

TABLE No. 6.—*Mean monthly temperatures at selected stations on Ohio River watershed*

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Bolivar, N. Y	23.0	21.3	33.6	43.5	54.9	62.5	66.8	65.4	59.2	48.7	37.1	25.1	45.1
Johnstown, Pa	30.1	29.3	39.5	49.6	61.4	69.4	73.4	71.0	65.7	53.7	41.7	32.6	51.5
Cadiz, Ohio	29.2	27.6	40.6	49.6	61.3	69.4	73.2	71.4	66.5	53.2	40.9	31.5	51.2
Danville, Ill	26.9	27.5	39.3	52.5	64.7	72.6	76.5	73.8	67.8	56.2	41.3	30.1	52.4
Columbus, Ohio	28.6	31.0	39.2	51.0	62.3	71.0	75.3	73.0	65.9	54.1	41.4	32.8	52.1
Indianapolis, Ind	28.2	30.7	39.7	52.4	63.3	72.4	76.2	73.6	66.7	55.0	41.6	32.6	52.7
Cincinnati, Ohio	32.3	34.4	42.8	54.3	65.1	73.7	77.7	75.5	69.0	57.0	44.6	36.4	55.2
Evansville, Ind	32.3	35.8	44.6	56.4	67.1	75.3	79.3	77.0	69.7	58.0	45.3	36.4	56.4
Lewisburg, W. Va	32.4	31.1	43.2	50.1	60.8	67.7	71.4	70.0	64.7	53.3	41.3	32.6	51.5
Eubank, Ky	34.9	33.3	46.3	53.8	64.2	71.1	74.7	73.8	68.9	56.7	44.5	35.7	54.8
Burkes Garden, Va	31.7	29.6	42.2	47.4	57.9	64.0	67.2	66.3	60.3	49.5	40.3	31.2	49.0
Nashville, Tenn	38.0	41.1	49.2	59.1	68.8	76.3	79.4	77.8	71.5	60.3	48.7	41.1	59.3
Knoxville, Tenn	37.5	40.8	48.2	57.4	66.5	73.4	76.2	74.7	69.4	58.1	47.1	39.7	57.4
Marshall, N. C	36.8	37.4	48.2	54.3	64.4	71.2	74.6	73.1	68.0	58.8	46.4	38.5	56.0
Chattanooga, Tenn	40.0	43.7	51.3	60.0	68.6	75.4	77.8	76.5	71.2	60.8	50.3	42.6	59.9
Florence, Ala	40.9	42.8	53.1	61.0	68.9	76.5	79.2	78.8	73.2	61.9	51.0	42.7	60.8
Average	32.7	33.6	43.9	53.3	63.8	71.4	74.9	73.2	67.4	56.0	44.0	35.1	54.1

NOTE.—Data from published records of United States Weather Bureau. Figures in all cases are averages for period of record at each observation station, to and including 1913.

RAINFALL

The mean annual rainfall over the whole basin is about 44 inches. As shown in Table No. 7, this precipitation corresponds approximately to that observed on watersheds of the Atlantic coast, such as the Connecticut, Delaware, Hudson, and Potomac, but is very considerably in excess of that upon the upper Mississippi and Missouri Basins.

TABLE No. 7.—*Mean annual rainfall on various watersheds of the United States*

Watershed	Area	Years included in record	Mean annual rainfall	Reference
	Sq. miles		*Inches*	
Tombigbee, above Columbus, Miss.	4,440	9	49.2	Trans. Am. Soc. Civil Engineers, vol. 79.
Delaware, above Trenton, N. J.	6,916	(1)	45.3	Geological Survey of New Jersey, Vol. 3, 1894.
Ohio, above mouth	202,691	(1)	44.4	Compiled from published records of U. S. Weather Bureau.
Hudson, above Mechanicsville, N. Y.	4,500	13	44.2	University of Wisconsin, Bull. No. 425.
Connecticut, above mouth	10,234	13	43.0	U. S. Geological Survey, Water Supply Paper No. 80.
James, above Cartersville, Va.	6,230	7	42.1	Trans. Am. Soc. Civil Engineers, vol. 79.
Illinois, in State of Illinois	23,940	(1)	35.4	Water Resources of Illinois, 1914.
Wisconsin, above Portage, Wis.	5,900	37	32.8	University of Wisconsin, Bull. No. 425.
Sacramento, above Red Bluff, Calif.	10,400	9	32.2	Trans. Am. Soc. Civil Engineers, vol. 79.
St. Croix, above St. Croix, Wis.	5,930	11	30.0	Do.
Colorado, above Austin, Tex.	37,000	10	26.9	Do.
Minnesota, above Montevideo, Minn.	6,300	5	22.7	Do.
South Platte, above Kersey, Colo.	10,000	6	17.3	U. S. Geological Survey, Water Supply Paper No. 75.

[1] Varies at different observation stations.

The distribution of rainfall on the major subdivisions of the Ohio watershed is shown in Table No. 8, the annual means being computed from the entire periods of record for all observation stations on the drainage basin up to 1913. As a rule the higher rainfalls occur in the eastern and southern portions of the watershed. Thus, the mean annual rainfall exceeds 40 inches upon the drainage areas of the Allegheny and Monongahela and of all tributaries entering the Ohio River from the south, while it is less than 40 inches upon the watersheds of all tributaries (excepting the Allegheny) entering from the north.

TABLE No. 8.—*Mean annual rainfall on Ohio Watershed above certain points and on principal tributary basins*

Drainage basin	Area	Mean annual rainfall	Drainage basin	Area	Mean annual rainfall
Ohio River:	*Sq. mi.*	*Inches*	Tributary basins (over 3,000 square miles in area).—Cont.:	*Sq. mi.*	*Inches*
Above Pittsburgh	19,020	42.97	Big Sandy	4,219	43.71
Above Cincinnati (including Licking)	76,320	41.66	Scioto	6,529	38.10
Including Tennessee	202,700	44.38	Licking	3,651	42.68
Tributary basins (over 3,000 square miles in area):			Miami	5,396	38.44
Allegheny	11,677	41.99	Kentucky	7,058	45.13
Monongahela	7,333	44.53	Green	9,154	46.30
Beaver	3,148	38.31	Wabash	32,476	39.46
Muskingum	7,989	37.98	Cumberland	17,936	49.46
Kanawha	12,073	43.93	Tennessee	40,608	50.59

On the watershed as a whole the rainfall usually reaches a maximum in March, with a second peak in June and July, declining to a minimum in October. Upon the northern and eastern watersheds the maximum is reached more commonly in July, while on the southern and western watersheds it falls more commonly in the early spring. Throughout the watershed the minimum rainfall occurs very constantly in October or November.

RUN-OFF

The mean annual run-off of the Ohio watershed for the years 1899 to 1910 according to records of the Geological Survey[3] was 20.2 inches, approximately 46 per cent of the rainfall. For that portion of the watershed above Cincinnati it was 16.7 inches, which is 40 per cent of the rainfall. As no records of discharge for years prior to 1914 are available for the other subdivisions of the watershed which are included in Table No. 8, their normal run-off can not be established; but the relations of rainfall to run-off in 1914–15 as indicated by special observations made in connection with this study are shown in detail in the tables included in Section II. (See Tables 16 and 17.)

[3] Unpublished records, furnished by courtesy of the Water Resources Branch, U. S. Geological Survey.

The seasonal distribution of run-off from the watershed differs materially from that of rainfall, the ratio of run-off to rainfall being much higher in winter and spring than in summer and autumn, so that notwithstanding the heavy rainfall of the summer the run-off in that portion of the year is characteristically low. The normal seasonal cycle of run-off in the Ohio Basin consists of:

(1) A maximum run-off period usually occurring between February and April, when the effects of rains are augmented by those of melting snow and ice and the ground is well saturated with moisture.

(2) A period of rapid subsidence of streams during early summer to low stages which continue throughout the warm season.

(3) A period of gradual increase in run-off during November and December, due to late autumn rains, until the maximum stage is again reached. (See figs. 4 and 5.)

The normal seasonal cycle of run-off is illustrated in the following summary, giving the average figures, in inches, of run-off, by months, of the Ohio watershed above Cincinnati for the years 1896 to 1913, inclusive:

	Run-off (in inches).		Run-off (in inches).
February	1. 94	August	0. 63
March	3. 26	September	. 43
April	2. 46	October	. 46
Total	7. 66	Total	1. 52
May	1. 53	November	. 61
June	. 99	December	1. 19
July	. 83	January	2. 19
Total	3. 35	Total	3. 99

Variations from this cycle may occur; for instance, a dry spring may be followed by a wet summer; and local rains may cause more or less variation in the normal seasonal curve upon limited drainage areas.

The geographical distribution of run-off over the Ohio Basin also varies seasonally. During the late winter and spring freshets the run-off from the northern sections of the watershed usually exceeds that from the southern portions, principally because of the influence of melting ice and snow. In the dry seasons, however, the run-off from southern watersheds having their headwaters in the mountains greatly exceeds that of many of the northern basins, largely due to physical conditions affecting the storage of ground water.

DISCHARGE

With respect to discharge, the Ohio River is the largest tributary of the Mississippi, although its drainage area is scarcely more than one-third that of the Missouri River. The mean annual discharge

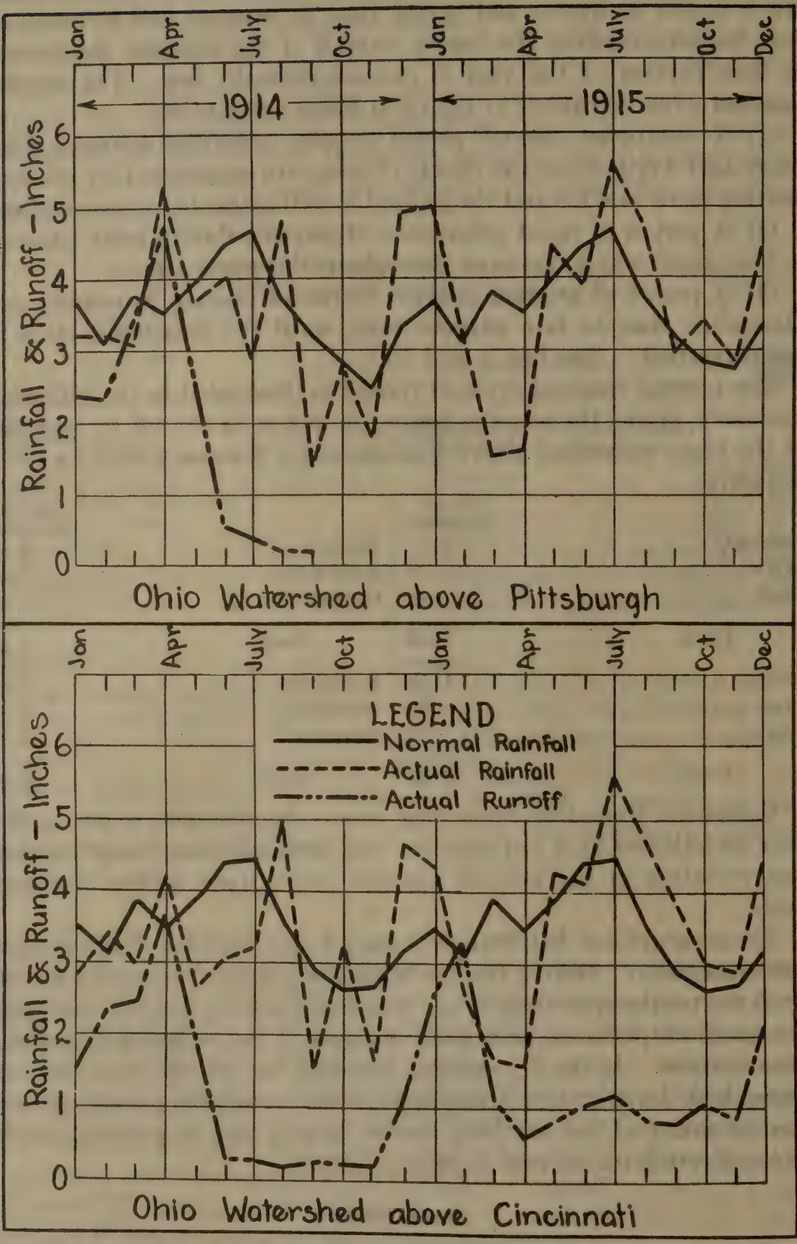

FIG. 4.—Rainfall and run-off on subdivisions of the Ohio River watershed, by months, 1914 and 1915, and normal rainfall for period of record

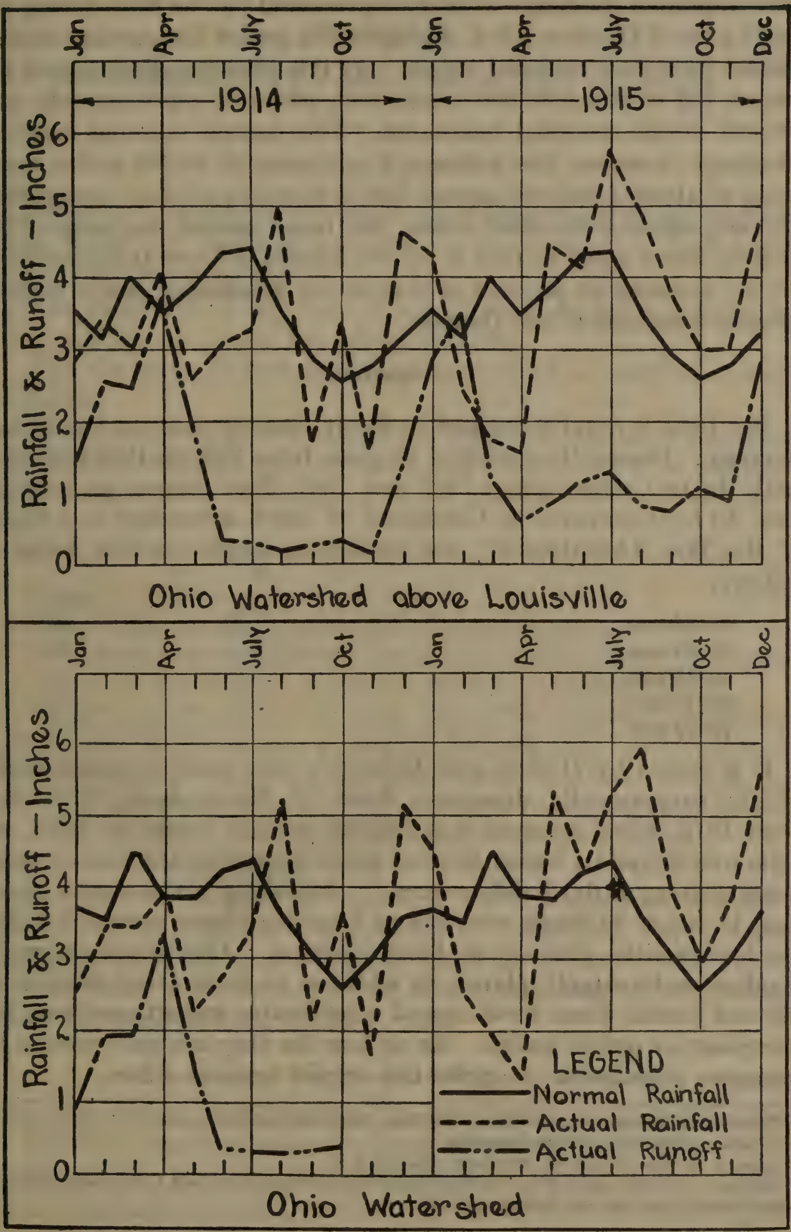

FIG. 5.—Rainfall and run-off on the Ohio River watershed above Louisville and on entire watershed, by months, 1914 and 1915, and normal rainfall for period of record

of the Ohio is about 300,000 second-feet,[4] while its maximum recorded discharge is about five times this amount, or 1,500,000 second-feet. The minimum discharge is fairly represented by the flow during the early part of October, 1914, during which period the stream reached almost its lowest recorded stages. At this time the discharge at the mouth fell to about 30,000 second-feet, which is approximately one-fiftieth of the recorded maximum. The normal seasonal range of discharge, however, lies between a minimum of 50,000 and a maximum of about 1,000,000 second-feet, a variation of about twentyfold. In comparison with other rivers, the mean annual discharge of the Ohio is about equal to that of the St. Lawrence River at Ogdensburg, N. Y.; is about 49 per cent of that of the Mississippi, and is slightly greater than that of the Danube.

FLOODS

The Ohio is notably subject to floods, causing more or less serious damage. During the period of 58 years from 1858 to 1913 inclusive, with the two earlier years 1832 and 1847, flood stages (gage height over 50 feet) occurred at Cincinnati 51 times, according to a report of the War Department [5], the maximum stages reached being as follows:

	Times
50–55 feet	25
55–60 feet	16
60–65 feet	6
65–70 feet	2
70–72 feet	2

It is stated by Horton and Jackson [6], who made a special study of the exceptionally disastrous flood of March-April, 1913 that from 1873, when accurate and reliable records begin, to 1913, the Ohio overflowed its banks at some point each year, and that in some years as many as five floods occurred. According to the same authorities, 43 out of 46 floods recorded at Cincinnati have occurred within the four months, January to April, inclusive. Due to the danger of flooding water-supply plants, in addition to their other dangers to life and health, these floods are of considerable importance from the viewpoint of public health. As to how far they are preventable by measures practicable of application expert opinion differs.

[4] The average discharge of the five-year period from 1880 to 1885 has been given by Mr. A. H. Horton, U. S. Geological Survey, at 303,000 second-feet.

[5] Jones, R. R., The Ohio River, War Dept., Doc. 537, p. 8.

[6] Horton, A. H., and Jackson, H. J., The Ohio Valley Flood of March-April, 1913, U. S. Geological Survey, Water Supply Paper No. 334, Washington, 1913.

Section II

MEASUREMENTS OF DISCHARGE AND VELOCITY

By H. W. Streeter

In order to interpret the results of the chemical and bacteriological studies which are discussed hereafter, it is necessary to have fairly precise determinations of:

1. The discharge of the Ohio River at each sampling station, at all stages observed during the period of study.
2. The discharge of each tributary upon which a sampling station was located.
3. The velocity of flow of the river between successive sampling stations and other points of special interest, from which to compute the time required for passage of water downstream between such points.

Prior to the beginning of this study, such data for the Ohio had not been assembled. The basic records from which the required estimates might be made were for the most part available, but scattered, chiefly in unpublished files of the United States Geological Survey and of the District Engineer offices on the Ohio River.

In order that the available data might be properly assembled, supplemented by necessary additional observations and analyzed, the services of an expert hydrographer were obtained through the courtesy of the Director of the United States Geological Survey who by request of the Surgeon General, detailed District Engineer C. E. Ellsworth to the work from March 1, 1914, to February 1, 1915. During a part of this time Mr. Ellsworth had the assistance of Junior Engineer R. M. Adams, United States Geological Survey; and throughout his work he was assisted by the engineers of the Public Health Service, who have continued and extended to subsequent periods the computations begun by him.

SOURCES OF DATA

The data found available from various sources and assembled by Mr. Ellsworth and his assistants were chiefly the following:

1. From the United States Geological Survey: Gage height records, discharge estimates, and rating tables for a number of gaging stations on the Ohio River and certain tributaries.
2. From the Ohio River District Engineer offices, United States Army Engineer Corps: Detailed topographic maps and profiles of

the Ohio River; records of gage heights at dams on this river and certain tributaries, and estimates of discharge.

3. From the United States Weather Bureau: Published records of rainfall at many points in the Ohio Basin, and both published and current unpublished records of gage heights for the many gages maintained upon the Ohio and its tributaries.

4. From the State Water Supply Commission of Pennsylvania: Gage-height records and individual stream gagings.

These data were supplemented by several months of field work by Mr. Ellsworth and his assistants, who made additional current-meter measurements at several previously established gaging stations, both on the main stream and on several tributaries; and located additional gaging stations on the Beaver, Scioto, Little Miami, Licking, and Miami Rivers. In order to provide rating tables for these streams, current-meter measurements were made at each station by Mr. Ellsworth during the summer of 1914, and after his detachment, additional measurements were made by engineers of the Public Health Service during the winter of 1914–15.

The estimates of discharge and velocity of flow derived from these records were compiled under Mr. Ellsworth's supervision, the preparation and checking of rating tables, tabulation of gage-height records, and computations of discharge being done partly at the headquarters of the Geological Survey in Washington, and partly in the Public Health Service laboratory at Cincinnati.

The hydrometric records assembled in the tables following are compiled and presented separately for two periods: The first from January 1 to October 15, 1914; the second from October 1, 1914, to December 31, 1915. They are thus separated because during the first period analytical studies were made at a series of six laboratories, covering stretches of the Ohio from Pittsburgh to Paducah, and all tributaries accessible from these stations, while during the second period, from October 15, 1914, work was carried on only at Cincinnati and Louisville, upon the stretch of river between these two cities, and upon the tributaries discharging into that stretch. Therefore, it has not been considered necessary to present detailed hydrometric data for other sections of the river beyond October 15, 1914.

As the hydrometric records have been compiled solely for application to other data assembled in this study, they are presented only in such detail as is necessary for this purpose; and since it is contrary to the policy of the United States Geological Survey to publish discharge rating tables, the same policy has been followed in this report. More detailed records than are here presented are, however, kept on file at the United States Public Health Service laboratory at Cincinnati, Ohio, where they are available to official agencies for reference in connection with future studies.

ESTIMATES OF DISCHARGE

Methods employed.—The methods employed in making estimates of discharge at the various points referred to in this report conform, in general, to those used by the United States Geological Survey, as described in various publications.[1] They comprise the following steps:

1. Establishment of a gage at some point on a stream at which changes in river stage are comparable with changes in discharge.
2. Current-meter measurements of the discharge of the stream upon an accurately determined section, located close to the gage, the measurements being made at a sufficient number of different gage heights to establish a definite curve of correlation between gage height and discharge.
3. Systematic observations of gage heights at intervals of a day or less, from records of which corresponding discharge values for any given period may be obtained by reference to the rating curve established as above.

The method of computing the discharge of a stream from an individual measurement consists in determining the mean velocity of flow in the selected cross section by means of the current meter, measuring the cross-sectional area of flow of this section by soundings, and from these two values obtaining the rate of discharge from the simple hydraulic formula:

$$Q = A\ V$$

in which,

Q = Discharge, in cubic feet per second.
A = Cross-sectional area of flow, in square feet.
V = Mean velocity of flow, in feet per second.

In the present work it has been necessary, in many instances, to extend estimates of discharge to points above or below gaging stations, because it was not always practicable to establish stations at precisely those points on the stream at which the discharge was required. In such cases the practice has been as follows:

1. Where it has been necessary to extend discharge estimates at a gaging station to some other point downstream, with no important tributary intervening, the discharge at the gaging station has been multiplied by a factor representing the increase in drainage area between the gaging station and the lower point of the stream, assuming that the increase in discharge is proportionate to the increase in drainage area. Such extension must usually be made in estimating the full discharge of a tributary, since it is necessary to locate gaging stations far enough upstream to avoid the influence of backwater.

[1] Hoyt, J. C., and Grover, N. C., River Discharge, Wiley & Sons, New York, 1st Edition. U. S. Geological Survey, Water Supply Papers 56 and 94.

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2. For extension of discharge estimates from a point immediately above to a point immediately below a tributary of known discharge, or vice versa, the discharge of the tributary has been either added to or subtracted from that indicated at the gaging station.

3. In extending estimates from a gaging station to some fairly distant point downstream, with one or more important tributaries intervening, a combination of methods (1) and (2) has been applied.

4. For estimates of discharge at a gaging station for periods during which gage-height records at the reference gage were missing, incomplete, or unreliable, gage heights have been estimated from a curve of correlation with some nearby gage for which the records were complete and satisfactory. This principle has necessarily been applied frequently in estimating the discharge of the Ohio River at gaging stations above movable dams, where the gages are in backwater when the controlling dams are raised. For example, the gaging station at Cincinnati is located only a few miles above Dam 37, hence the reference gage (U. S. Weather Bureau gage at Cincinnati) is in backwater when the wickets of this dam are up. Gage heights corresponding to open-channel conditions must, therefore, be taken from a curve of correlation between this gage and the one situated below Dam 37, this correlation having been previously established from simultaneous readings on the two gages during open-channel conditions. The correlation between these two gages is shown graphically in Figure 6 which is given as an illustration of the several similar curves used.

5. In making estimates of the discharge of the Monongahela, it has been necessary to take the sum of the discharges of four important tributaries, with due allowance for proportionate run-off from the remainder of the watershed, since a series of permanent dams makes it impracticable to locate a satisfactory gaging station upon the main stream.

The estimates of discharge at many points obviously lack the precision requisite in a finished hydrometric survey. They are, however, the best obtainable from the data at hand, and are believed to be sufficiently precise for the purposes to which they are applied. The estimates of mean monthly discharge of the main stream are considered to be subject to a probable error not exceeding 10 per cent, in most cases less than 5 per cent. Estimates for some of the tributaries are subject to somewhat greater errors, largely because of difficulties in obtaining accurate gage readings.

A list of all gages, sampling stations, tributary outlets and dams of the Ohio referred to in this report is given in Table No. 9, locations being given in miles from the confluence of the Allegheny and Monongahela Rivers at Pittsburgh, measured along the left bank of the

stream at the low-water line, as shown on topographic maps compiled by the United States Army Engineer Corps.[2]

In explanation of the terms "upper," "lower," and "middle" as applied to gage at Ohio River dams, it is customary to establish three gages at each dam. A temporary gage, designated as the "middle" gage, because of its location at the site of the dam itself, is established as the first step in the construction of the dam. Later, two gages are added, an "upper" gage, immediately above the dam, indicating pool level when the dam is raised, and a "lower"

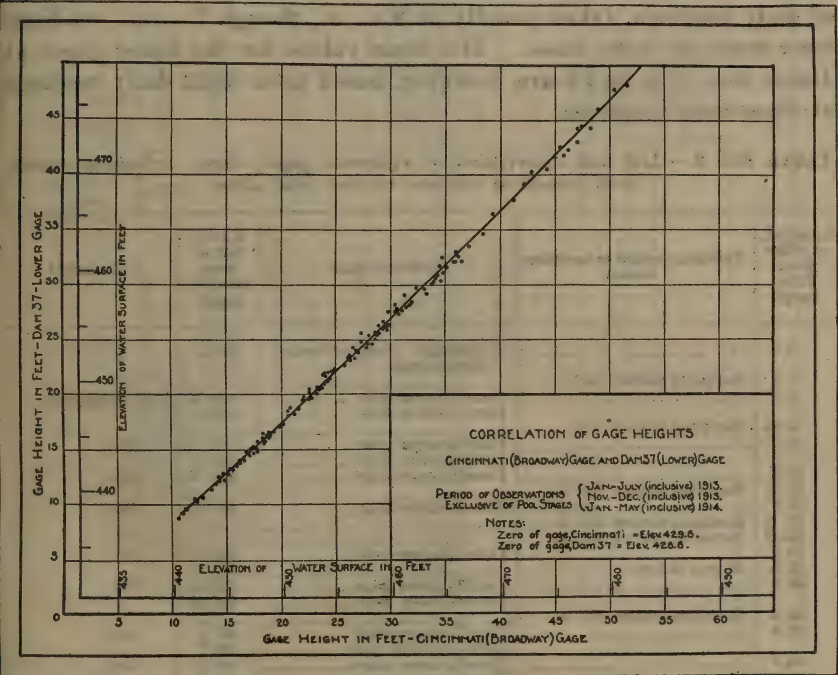

FIG. 6

gage, immediately below the dam, indicating river stages in the downstream channel.

Figure 7 shows the location of the gages, tributaries, and sampling stations listed in Table 9, in relation to distance from the confluence and to a profile of the river, the latter being taken from the Report of Examination of the Ohio River, by the War Department.[3] Table No. 10 lists the gaging stations upon the main stream of the Ohio, for which discharge estimates were made, and indicates the sampling stations to which each discharge is applied, as well as the method used

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[2] These maps are accessible in original tracings on file at the District Engineer Offices, United States Army Engineer Corps, at Cincinnati and Louisville.

[3] H. Doc. No. 492, 60th Cong., 1st sess., 1907–1908.

in estimating the discharge. Table No. 11 gives a similar description of gaging stations upon tributaries from which samples were collected, the sampling station being located in each case at the mouth of the tributary.

Gage heights and discharges recorded during 1914 and 1915.—Monthly mean gage heights at all gages used for any purpose during the period from January 1 to October 15, 1914, are given in Table No. 12, while Table No. 13 gives gage heights at the smaller number of gages used during the period from October 1, 1914, to December 31, 1915. Each value given in these tables is the mean of daily readings, taken usually at 8 a. m., though 7 a. m., readings were made in some cases. The mean values for the lower gages at Dams Nos. 1, 6, and 8 are, however, based upon eight daily readings at three-hour intervals.

TABLE No. 9.—*List and description of reference gages, dams, tributary outlets, and sampling stations on the Ohio River*

Location, in miles, from Pittsburgh	Tributary outlet or sampling station	Reference gage	Elevation of zero point of gage[1]	Remarks[2]
0. 0		Pittsburgh Point—Weather Bureau gage.	697. 2	
3. 1	Sampling station No. 3			
4. 7		Dam 1, upper gage	690. 74	Dam completed.
		Dam 1, lower gage	690. 6	
5. 28	Sampling station No. 5			
9. 0		Dam 2, upper gage	683. 13	Do.
		Dam 2, lower gage	683. 1	
10. 9		Dam 3, upper gage	675. 24	Do.
11. 81	Sampling station No. 11			
18. 6		Dam 4, upper gage	667. 75	Do.
19. 11	Sampling station No. 19			
23. 12	Sampling station No. 23			
23. 9		Dam 5, upper gage	662. 11	Do.
25. 0	Beaver River			
28. 8		Dam 6, upper gage	654. 94	Do.
		Dam 6, lower gage	654. 94	
29. 3	Sampling station No. 29			
36. 9		Dam 7, upper gage	647. 2	Do.
		Dam 7, middle gage	649. 7	
46. 1		Dam 8, upper gage	640. 3	Do.
		Dam 8, lower gage	637. 3	
55. 5		Dam 9, middle gage	635. 3	Dam not completed
65. 30	Sampling station No. 65			
65. 7		Dam 10, middle gage	626. 2	Do.
76. 3		Dam 11, upper gage	618. 1	Dam completed.
		Dam 11, middle gage	619. 1	
		Dam 11, lower gage	615. 1	
77. 15	Sampling station No. 77			
87. 0		Dam 12, middle gage	614. 0	Dam not completed
88. 0	Sampling station No. 88			
89. 8		Wheeling, Weather Bureau gage.	610. 6	
95. 8		Dam 13, upper gage	604. 0	Dam completed.
		Dam 13, middle gage	605. 0	
		Dam 13, lower gage	601. 0	
96. 7	Sampling station No. 97			
103. 74	Sampling station No. 104			
113. 8		Dam 14, middle gage	595. 4	Dam not completed
128. 9		Dam 15, middle gage	588. 3	Do.
146. 4		Dam 16, middle gage	580. 6	Do.
154. 8		St. Marys, W. Va., Weather Bureau gage.		
167. 4		Dam 17, middle gage	573. 5	Do.
171. 7	Muskingum River			

[1] Datum, mean sea level at Sandy Hook, N. J.
[2] Status of construction of dams in the Ohio River as of Dec. 31, 1914.

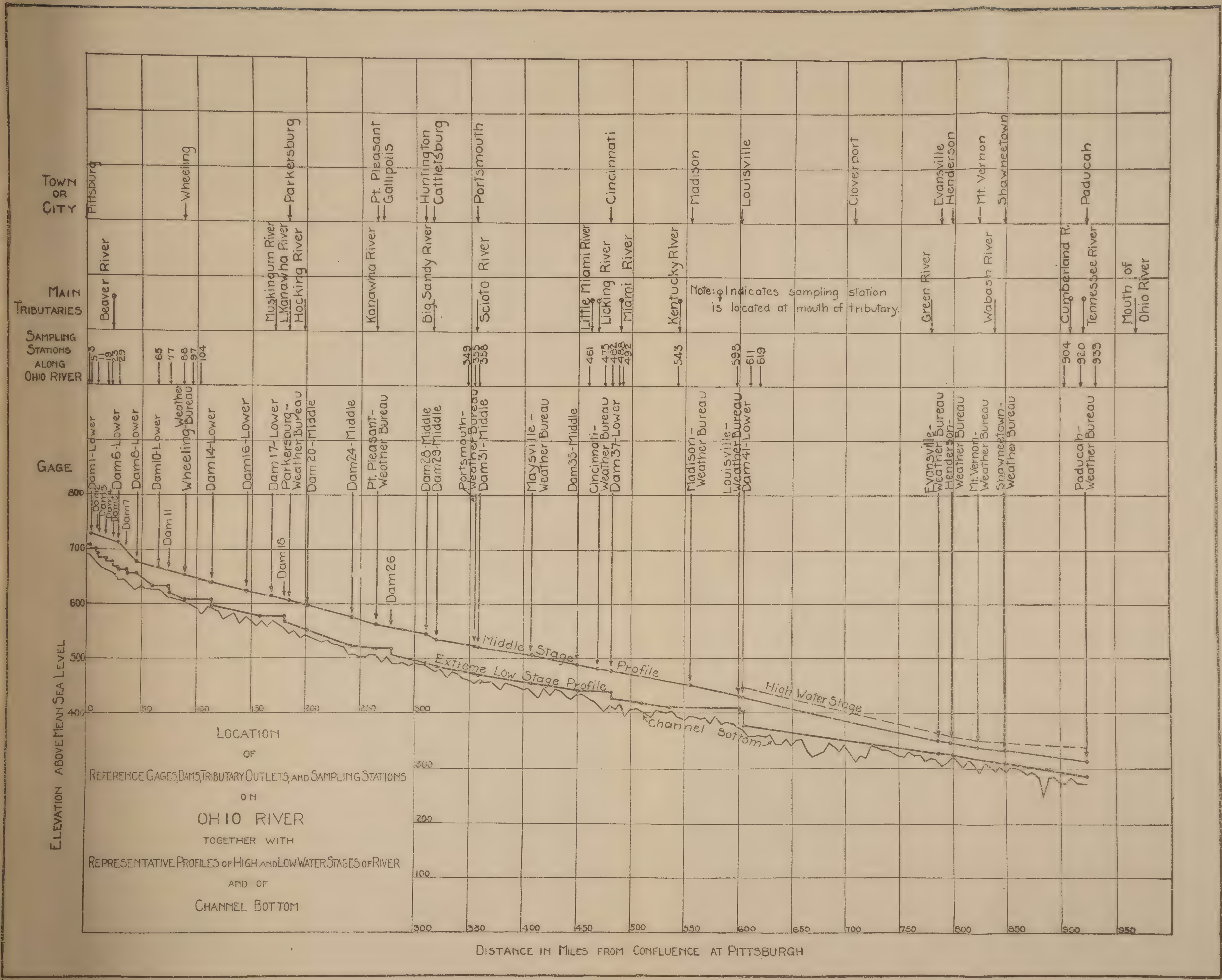
LOCATION OF REFERENCE GAGES, DAMS, TRIBUTARY OUTLETS, AND SAMPLING STATIONS ON OHIO RIVER TOGETHER WITH REPRESENTATIVE PROFILES OF HIGH AND LOW WATER STAGES OF RIVER AND OF CHANNEL BOTTOM
TOWN OR CITY
MAIN TRIBUTARIES
SAMPLING STATIONS ALONG OHIO RIVER
GAGE
ELEVATION ABOVE MEAN SEA LEVEL
DISTANCE IN MILES FROM CONFLUENCE AT PITTSBURGH
Pittsburg
Wheeling
Parkersburg
Pt. Pleasant
Gallipolis
Huntington
Catlettsburg
Portsmouth
Cincinnati
Madison
Louisville
Cloverport
Evansville
Henderson
Mt. Vernon
Shawneetown
Paducah
Beaver River
Muskingum River
L. Kanawha River
Hocking River
Kanawha River
Big Sandy River
Scioto River
Little Miami River
Licking River
Miami River
Kentucky River
Green River
Wabash River
Cumberland R.
Tennessee River
Mouth of Ohio River
Note: Indicates sampling station is located at mouth of tributary.
Dam 1-Lower
Dam 6-Lower
Dam 8-Lower
Dam 10-Lower
Wheeling Weather Bureau
Dam 14-Lower
Dam 16-Lower
Dam 17-Lower
Parkersburg-Weather Bureau
Dam 20-Middle
Dam 24-Middle
Pt. Pleasant-Weather Bureau
Dam 28-Middle
Dam 29-Middle
Portsmouth-Weather Bureau
Dam 31-Middle
Maysville-Weather Bureau
Dam 35-Middle
Cincinnati-Weather Bureau
Dam 37-Lower
Madison-Weather Bureau
Louisville-Weather Bureau
Dam 41-Lower
Evansville-Weather Bureau
Henderson-Weather Bureau
Mt. Vernon-Weather Bureau
Shawneetown-Weather Bureau
Paducah-Weather Bureau
Dam 7
Dam 11
Dam 18
Dam 26
Middle Stage Profile
Extreme Low Stage Profile
High Water Stage
Channel Bottom
5
13
19
23
29
65
77
88
97
104
349
355
358
461
475
482
488
492
543
598
611
619
904
920
933
800
700
600
500
400
300
200
100
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950

FIG. 7

TABLE No. 9.—*List and description of reference gages, dams, tributary outlets, and sampling stations on the Ohio River*—Continued

Location, in miles, from Pittsburgh	Tributary outlet or sampling station	Reference gage	Elevation of zero point of gage	Remarks
179.3		Dam 18, upper gage	564.2	Dam completed.
		Dam 18, lower gage	561.2	
184.2	Little Kanawha River	Parkersburg, W. Va., Weather Bureau gage.	561.6	
191.4		Dam 19, middle gage	557.2	Dam not completed.
198.6	Hocking River			
201.7		Dam 20, middle gage	550.7	Do.
220.1		Dam 22, middle gage		Do.
242.0		Dam 24, middle gage	521.6	Do.
264.2		Point Pleasant, W. Va., Weather Bureau gage.	509.4	
264.8	Kanawha River			
269.2		Gallipolis, Ohio, Weather Bureau gage.	509.3	
278.0		Dam 26, upper gage	502.6	Dam completed.
310.9		Dam 28, middle gage	492.0	Dam not completed.
316.5	Big Sandy River	Catlettsburg, Ky., Weather Bureau gage.	487.3	
319.4		Dam 29, middle gage	484.8	Do.
338.9		Dam 30		Do.
349.45	Sampling station No. 349			
355.3		Portsmouth, Ohio, Weather Bureau gage.	470.9	
355.37	Sampling station No. 355			
355.5	Scioto River			
358.22	Sampling station No. 358			
358.4		Dam 31, middle gage	470.0	Do.
407.3		Maysville, Ky., Weather Bureau gage.	446.7	
449.7		Dam 35, middle gage	442.8	Do.
461.4	Sampling station No. 461			
462.5	Little Miami River			
468.2		Cincinnati, Ohio, Weather Bureau gage.	429.76	
468.5	Licking River			
475.04	Sampling station No. 475			
481.3		Dam 37, upper gage	428.8	Dam completed.
		Dam 37, lower gage	428.8	
482.33	Sampling station No. 482			
488.21	Sampling station No. 488			
489.4	Miami River			
492.45	Sampling station No. 492			
543.0	Sampling station No. 543			
543.3	Kentucky River			
555.5		Madison, Ind., Weather Bureau gage.	403.2	
597.79	Sampling station No. 598			
601.5		Louisville, Ky., Weather Bureau gage.	403.0	
604.0		Dam 41, upper gage	403.0	Dam not completed.
		Dam 41, lower gage	376.06	
611.02	Sampling station No. 611			
618.73	Sampling station No. 619			
707.6		Cloverport, Ky., Weather Bureau gage.		
778.8	Green River			
787.0		Evansville, Ind., Weather Bureau gage.	329.2	
797.9		Henderson, Ky., Weather Bureau gage.	327.4	
804.1		Dam 48, middle gage	325.1	Do.
823.0		Mount Vernon, Ohio, Weather Bureau gage.	315.4	
840.5	Wabash River			
848.9		Shawneetown, Ill., Weather Bureau gage.	309.3	
903.7	Sampling station No. 904			
909.8	Cumberland River			
921.19	Sampling station No. 920			
922.1	Tennessee River			
924.1		Paducah, Ky., Weather Bureau gage.	286.3	
926.51	Sampling station No. 926			
934.14	Sampling station No. 933			
938.3	Sampling station No. 938			
968.51	Mouth of Ohio River			

TABLE NO. 10.—*List and description of gaging stations and other points on Ohio River for which discharge estimates have been made*

Location, miles from Pittsburgh	Points at which discharge estimated	Reference gage	Method of estimating discharge	Sampling stations to which discharge applied
0–25	Pittsburgh, Pa.	Dam 1, lower gage	Open channel at Dam 1 gage: From USGS rating curve at Dam 1	3–23
		None	Backwater at Dam 1 gage: (Discharge at East Liverpool)−1.4×(discharge of Beaver).	
26	Below Beaver River	None	(Discharge at Pittsburgh)+(discharge of Beaver River)	29
44	East Liverpool, Ohio	Dam 6, lower gage	Open channel at Dam 6 gage: From USGS rating curve at East Liverpool	----------
		Dam 8, lower gage	Backwater at Dam 6 gage: From East Liverpool rating curve and relationship curve between gage heights at lower gages of Dam 6 and Dam 8.	----------
90	Wheeling, W. Va.	Wheeling, Weather Bureau	Open channel at Wheeling gage: From USGS rating curve at Wheeling	65–104
			Backwater at Wheeling gage: From Wheeling rating curve and relationship curve between gage heights at Wheeling and Dam 13, lower gage.	----------
114–172	Between Dam 14 and Muskingum River	None	(Discharge at Wheeling)×1.06×(run-off between Wheeling and Parkersburg)÷(run-off at Wheeling).	None.
185	Below Little Kanawha River	Parkersburg, W. Va., Weather Bureau.	From USGS rating curve at Parkersburg	None.
199–265	Between Hocking and Kanawha Rivers	None	1.04×(discharge at Parkersburg)	None.
265	Below Kanawha River	Point Pleasant, W. Va., Weather Bureau.	From USGS rating curve at Point Pleasant	None.
317–355	Above Scioto River	None	(Discharge at Point Pleasant)×1.17×(run-off at point between Point Pleasant and Scioto River)÷(run-off at Point Pleasant).	349–355
356	Below Scioto River	None	(Discharge above Scioto River)+(discharge of Scioto River)	358
462	Above Little Miami River	None	(Discharge below Licking)−(discharge of Licking River)−(Discharge of Little Miami River).	461
463	Below Little Miami River	None	(Discharge below Licking River)−(discharge of Licking River)	None.
469	Below Licking River	Cincinnati, Ohio, Weather Bureau.	Open channel at Cincinnati gage: From USGS rating curve at Cincinnati	475–488
		Dam 37, lower gage	Backwater at Cincinnati gage: From Cincinnati rating curve and relationship curve between gage heights at Cincinnati and Dam 37, lower gage.	----------
490	Below Miami River	None	(Discharge below Licking)+(discharge of Miami River)	492
543	Above Kentucky River	None	1.015×(discharge below Miami River)	543
544	Below Kentucky River	None	(Discharge above Kentucky River)+(discharge of Kentucky River)	None.
602	Louisville, Ky.	Dam 41, lower gage	From USGS rating curve at Louisville	598–619
619–778	Between Sampling Station 619 and Green River.	None	1.05×(discharge at Louisville)	None.
787	Evansville, Ind.	Evansville, Weather Bureau	From USGS rating curve at Henderson, Ky.	None.
909	Below Wabash River	None	(Discharge at Evansville)+(discharge of Wabash River)	904
910–922	Below Cumberland River	None	(Discharge above Cumberland River)+(discharge of Cumberland River)	920
923	Below Tennessee River	None	(Discharge above Cumberland River)+(discharge of Tennessee River)	926–933

TABLE No. 11.—*List and description of gaging stations used on streams tributary to Ohio River*

[Abbreviations: USPHS=United States Public Health Service; USGS=United States Geological Survey; Pa. Wat. Sup. Comm.=Pennsylvania Water Supply Commission]

Stream on which located	Gaging station: Location above mouth	Gaging station: Designation	Reference gage	Method of estimating discharge at mouth of tributary
	Miles			
West Fork River		Enterprise, W. Va., USGS	Enterprise, USGS	Applied to estimating discharge of Monongahela River at its mouth. Sum of discharge at the four tributary gaging stations multiplied by a factor, 1.3 obtained by combining ratios of watershed areas and of run-off for the total area of the Monongahela basin and that above the gaging stations.
Tygart River		Fetterman, W. Va., USGS	Fetterman, USGS	
Cheat River		Morgantown, W. Va., USGS	Morgantown, USGS	
Youghiogheny River	[1] 55	Connelisville, Pa., Pa. Wat. Sup. Comm.	Connellsville, Pa. Wat. Sup. Comm.	
Allegheny River	29	Freeport, Pa., USGS and USPHS.	Freeport, Weather Bureau	Discharge at Freeport taken as that at mouth.
Shenango River		Sharon, Pa., Pa. Wat. Sup. Comm.	Sharon, Pa., Wat. Sup. Comm.	Applied to estimating discharge of Beaver River at Wampum, Pa., for period not covered by gage readings at Wampum.
Slippery Rock Creek		Wurtemburg, Pa., Pa. Wat. Sup. Comm.	Wurtemburg, Pa., Wat. Sup. Comm.	Applied to estimating discharge of Connoquenessing Creek near Ellwood City, Pa., for period not covered by gage readings near Ellwood City.
Connoquenessing Creek	13	Ellwood City, Pa., USPHS	Ellwood City, Pa., USPHS	Applied to estimating discharge of Beaver River at its mouth by addition to discharge of Beaver River at Wampum, Pa., correcting for increase in drainage area.
Beaver River		Wampum, Pa., USPHS	Wampum, USPHS	Applied to estimating discharge of Beaver River at its mouth, as above described.
Scioto River	70	Chillicothe, Ohio, USPHS	Chillicothe, USPHS	Discharge at mouth=discharge at Chillicothe times 2.0.
Little Miami River		Plainville, Ohio, USPHS	Plainville, USPHS	Discharge at Plainville taken as discharge at mouth.
Licking River		Falmouth, Ky., USPHS	Falmouth, Weather Bureau	Discharge at mouth=1.59×(discharge at Falmouth).
Miami River	35	Hamilton, Ohio, USPHS	Hamilton, USGS and USPHS.	Discharge at mouth=1.51×(discharge at Hamilton).
Kentucky River	55	Frankfort, Ky., USGS	Lock 4, U. S. Army Eng. Corps.	Discharge at mouth=1.28×(discharge at Frankfort).
Wabash River	80	Mount Carmel, Ill., USGS	Mount Carmel, Weather Bureau.	Discharge at mouth=1.15×(discharge at Mount Carmel).
Cumberland River	190	Nashville, USGS, U. S. Army, Eng. Corps, USPHS.	Nashville, Weather Bureau	Discharge at mouth=1.30×(discharge at Nashville).
Tennessee River		Johnsonville, Tenn., USGS	Johnsonville, Weather Bureau	Discharge at mouth=1.04×(discharge at Johnsonville).

[1] Above mouth of Monongahela River.

TABLE NO. 12.—*Monthly mean gage heights, in feet, at all reference gages used on Ohio River and tributary streams (Jan. 1 to Oct. 15, 1914)*

River	Gage	Location from Pittsburgh	Gage heights, in feet, 1914									
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct. 1–15
		Miles										
Ohio	Pittsburgh, Pa., Weather Bureau	0.0	5.8	6.4	7.7	11.0	6.9	5.8	6.1	6.0	6.0	6.1
Do	Dam 1, lower gage	4.7	7.2	7.4	8.6	11.4	8.7	8.9	8.1	9.0	9.1	
Do	Dam 2, upper gage	9.0	7.1	7.3	8.8	11.2	10.3	15.8	15.4	16.4	16.5	
Do	Dam 3, upper gage	10.9	10.0	10.5	12.1	15.4	12.7	16.4	16.3	16.3	16.6	
Do	Dam 4, upper gage	18.6						15.8	16.2	16.4	16.4	
Do	Dam 5, upper gage	23.9						13.9	14.4	14.6	14.4	
Do	Dam 6, upper gage	28.8						12.9	13.2	13.5	13.3	
Do	Dam 6, lower gage [1]	28.8	11.1	11.4	13.5	17.6	11.6	5.0	3.6	3.1	5.2	
Do	Dam 7, middle gage	36.9	10.3	10.6	12.6	16.8	10.9	4.1	2.8	4.5		
Do	Dam 8, upper gage	46.1								15.0	15.3	
Do	Dam 8, lower gage [1]	46.1	12.0	12.4	14.3	18.2	12.5	6.0	4.6	4.0	3.8	
Do	Dam 9, middle gage	55.6	9.7	10.3	12.1	15.9	10.2	3.7	2.5	1.9	1.6	
Do	Dam 10, lower gage	65.7	9.9	10.6	12.7	17.4	11.1	7.6	7.7	7.4	7.0	
Do	Wheeling, W. Va., Weather Bureau [1]	89.8	10.7	10.6	13.0	18.5	11.4	6.1	7.8	8.2	8.0	7.8
Do	Dam 14, middle gage	113.8	11.3	12.4	13.9	20.3	12.0	3.7	2.3	1.7	1.7	.2
Do	Dam 16, middle gage	146.4	10.2	12.1	12.9	19.1	11.4	3.6	2.5	1.4	1.4	2.3
Do	Dam 17, middle gage	167.4	9.9	11.5	12.5	17.5	10.6	5.6	5.3	4.9	3.9	3.4
Do	Parkersburg, W. Va., Weather Bureau [1]	184.2	12.1	13.3	15.0	21.4	12.7	5.0	4.2	3.1	3.1	1.0
Do	Dam 20, middle gage	201.7	10.7	13.1	14.0	21.4	11.8	3.6	2.9	2.1	2.1	.1
Do	Dam 24, middle gage	242.0	13.6	17.0	17.6	27.7	14.6	4.0	3.5	2.8	2.6	—0.1
Do	Point Pleasant, W. Va., Weather Bureau [1]	264.2	14.4	18.1	18.0	27.1	14.0	3.1	3.0	1.8	2.1	.2
Do	Dam 28, middle gage	310.9	16.0	21.0	20.8	30.4	16.5	4.4	4.5	3.3	3.7	1.3
Do	Dam 29, middle gage	319.4			24.6	34.4	19.5	5.1	4.9	3.1	3.9	.6
Do	Portsmouth, Ohio, Weather Bureau	355.3	18.5	25.1	24.5	34.3	20.0	5.8	5.4	4.0	4.6	1.9
Do	Maysville, Ky., Weather Bureau	407.3	18.3	24.8	21.9	33.7	20.8	6.1	5.4	5.2	4.7	2.3
Do	Dam 35, middle gage	449.7	15.0	21.9	21.6	30.5	17.5	4.2	4.0	2.7	3.4	1.0
Do	Cincinnati, Ohio, Weather Bureau [1]	468.2	20.0	28.3	27.0	36.3	22.8	10.9	11.8	11.6	11.8	11.4
Do	Dam 37, lower gage [1]	481.3	17.3	25.3	24.0	32.7	19.9	5.3	4.9	3.7	4.4	1.3
Do	Madison, Ind., Weather Bureau	555.5	17.4	25.5	23.9	31.2	20.4	9.1	9.2	8.8	8.8	7.8
Do	Dam 41, lower gage [1]	604.0	17.6	29.1	26.4	36.0	21.4	6 9	6.0	5.1	5.5	2.9
Do	Evansville, Ind., Weather Bureau [1]	787.0	14.7	26.4	22.4	31.4	21.2	6.3	4.8	4.0	5.5	3.5
Do	Mount Vernon, Ind., Weather Bureau	823.0	14.2	25.0	22.9	30.9	19.9	6.2	4.3	3.6	5.0	3.2
Do	Paducah, Ky	924.1	10.2	21.4	21.1	31.1	18.5	6.0	4.4	2.5	4.6	2.0
Tributaries		*Above mouth*										
Allegheny	Freeport, Pa., USGS and USPHS [1]	28.7	6.6	11.3	12.8	11.5	10.2	3.6	2.1	1.4	1.6	.9
Monongahela	Lock 10, lower gage [1]		10.0	9.9	10.2	11.1	8.1	6.9	7.2	7.0	6.6	6.4
Beaver	Wampum, Pa., USPHS [1]								.6	.5	.5	.3

Scioto	Chillicothe, Ohio, Weather Bureau [1]	70.0	2.2	5.5	7.2	6.1	2.8	.1	−0.1	−0.1	−0.1	−0.3
Little Miami	Plainville, Ohio, USPHS [1]									6.4	5.9	5.8
Licking	Falmouth, Ky., Weather Bureau [1]		3.7	8.1	5.5	5.0	3.9	2.0	1.2	1.8	1.4	1.7
Miami	Hamilton, Ohio, USGS, upper gauge [1]	35	3.4	4.4	5.5	5.4	3.5	2.6	2.5	2.5	2.4	2.1
Cumberland	Nashville, Tenn., USGS, USA, and USPHS	190					12.9	7.9	8.7	8.5	8.4	7.5
Tennessee	Johnsonville, Tenn., USGS [1]						6.3	2.1	2.2	2.0	1.5	.4

TABLE No. 13.—*Monthly mean gage heights, in feet, at all reference gages used on Ohio River and tributary streams, (Oct. 1, 1914, to Dec. 31, 1915)*

River	Gage	Location, from Pittsburgh	Gage heights in feet														
			1914			1915											
			Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
		Miles															
Ohio	Dam 1, lower gage [1]	4.7	9.1	9.2	6.2	9.2	11.2	4.8	7.1	8.7	8.6	8.2	8.9	9.3	8.1	8.6	9.5
Do	Dam 6, lower gage [1]	28.8	7.9	7.9	8.7	13.9	17.2	8.0	8.4	9.7	8.9	8.8	9.0	8.0	8.8	8.8	12.2
Do	Dam 8, lower gage [1]	46.1	3.1	7.6	9.8	14.7	17.9	8.9	9.0	10.6	10.0	10.0	10.1	9.4	9.9	9.9	13.3
Do	Dam 9, lower gage	55.6	1.1	2.9	8.8	13.8	16.9	8.4	7.1	8.3	7.4	8.1	7.8	5.3	7.8	7.9	11.2
Do	Dam 10, lower gage	65.7	7.5	7.4	8.0	13.2	16.7	6.7	7.4	8.9	8.4	8.0	7.1	6.9	7.8	8.9	12.6
Do	Dam 14, middle gage	113.8	.9	1.6	8.8	14.9	19.0	7.5	6.1	7.6	6.6	7.5	6.7	4.1	6.9	6.4	11.9
Do	Dam 16, middle gage	146.4	.9	1.1	8.7	14.4	18.5	7.3	5.7	7.3	6.7	7.5	6.7	3.9	6.7	6.1	11.6
Do	Dam 17, middle gage	167.4	4.0	4.6	8.9	13.3	17.6	7.6	6.6	7.9	7.6	7.7	7.6	6.4	7.5	7.4	11.6
Do	Dam 28, middle gage	310.9	2.5	2.8	14.5	24.5	28.0	12.6	8.2	9.6	10.7	10.8	8.5	8.0	10.7	9.2	17.8
Do	Portsmouth, Ohio, Weather Bureau	353.3	3.5	3.5	16.6	27.7	32.0	15.6	10.3	12.1	13.8	14.2	11.6	11.0	13.6	11.9	21.3
Do	Maysville, Ky., Weather Bureau	407.3	3.8	3.5	16.2	27.6	32.0	15.8	10.3	11.8	13.8	13.9	11.9	10.4	13.4	11.3	21.2
Do	Dam 35, middle gage	449.7	2.5	2.2	12.9	23.6	28.7	12.9	7.8	9.1	11.1	11.2	8.9	8.4	10.9	9.1	18.7
Do	Cincinnati, Ohio, Weather Bureau [1]	468.2	11.7	11.7	18.6	29.6	35.2	17.9	11.8	14.7	16.7	17.3	13.9	13.8	16.1	15.9	24.2
Do	Dam 37, lower gage [1]	481.3	3.7	2.8	15.2	26.2	31.9	15.4	9.6	11.3	13.9	14.2	11.6	10.3	13.0	11.0	21.4
Do	Madison, Ind., Weather Bureau	555.5	9.2	8.6	16.2	25.6	30.9	16.7	12.0	13.2	15.5	16.4	13.3	12.9	14.7		
Do	Dam 41, lower gage [1]	604.0	5.5	3.9	16.2	29.1	36.1	16.5	10.0	11.9	15.8	16.8	12.4	11.7	14.3	12.6	25.4
		Above mouth															
Little Miami	Plainville, Ohio, USPHS [1]		6.7	5.9	7.6	8.8	11.8	7.2	6.4	6.6	7.8	7.9	8.5	8.3	7.6	7.1	9.2
Licking	Falmouth, Ky[1].		3.2	1.5	5.2	6.7	6.8	4.1	2.5	4.2	4.0	5.4	3.2	2.3	3.3	3.8	9.4
Miami	Hamilton, Ohio USPHS	35	2.5	2.2	2.8	4.3	6.4	4.1	3.7	3.9	4.4	5.6	4.7	4.8	4.4	4.1	4.8
Kentucky	Frankfort, Ky., Lock 4, lower gage [1]	55	7.5	6.4	8.6	10.2	9.8	8.6	7.3	7.5	8.1	9.3	7.8	7.1	8.1	8.3	14.9

[1] Gages employed in estimation of discharge.

Tables Nos. 14 and 15, respectively, show, for the same two periods, the monthly mean discharge, in second-feet, of the Ohio River at points essential to this study, and of those tributaries from which samples were taken, also of the Wabash River from which no samples were taken. In Tables Nos. 16 and 17 the monthly run-off from designated portions of the Ohio watershed, and from the watersheds of the same tributaries, is given for the same two periods in terms of the depth in inches to which each drainage area would have been covered had all the water flowing from it in each month been conserved and uniformly distributed over its surface. The values given are derived directly from those of Tables Nos. 14 and 15 using basin areas obtained largely from data published by the United States Geological Survey,[4] as given in Tables Nos. 2 and 3, Section I.

TABLE No. 14.—*Monthly mean discharge, in thousands of second-feet, of Ohio River at designated points and of certain tributaries at their mouths (Jan. 1 to Oct. 15, 1914)*

	Discharge in thousand second-feet									
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct. 1–15
Ohio River										
At Pittsburgh, Pa	38.8	42.2	57.2	79.2	42.2	9.38	5.38	3.73	3.37	1.67
Below Beaver River	46.9	46.0	65.3	91.0	49.7	10.2	5.84	4.09	3.76	1.91
At East Liverpool, Ohio	48.6	50.6	70.9	98.2	52.5	10.3	6.00	4.23	3.92	2.22
At Wheeling, W. Va	47.0	56.8	71.4	109.0	55.7	10.3	6.63	4.65	4.50	2.47
Between Dam 14 and Muskingum River	48.4	59.7	73.5	114.0	56.8	10.6	7.04	4.93	4.86	2.47
Below Little Kanawha River	59.0	76.4	88.2	151.0	66.1	12.9	9.63	6.90	7.40	2.54
Between Hocking and Kanawha Rivers	61.5	79.5	91.8	157.0	68.8	13.5	10.0	7.18	7.71	2.63
Below Kanawha River	85.8	117.0	116.0	185.0	85.8	16.0	14.9	9.78	11.4	3.79
Above Scioto River	90.8	138.0	133.0	210.0	101.0	17.9	16.4	11.8	13.7	4.44
Below Scioto River	95.8	152.2	152.1	227.2	108.0	18.9	17.1	12.8	14.5	4.93
Above Little Miami River	94.9	156.1	147.7	237.1	120.0	19.8	18.7	13.9	17.1	7.21
Below Little Miami River	96.3	159.8	153.2	242.3	122.0	20.0	18.9	14.5	17.3	7.45
Below Licking River	99.7	173.0	160.0	248.0	126.0	21.0	19.0	15.2	17.5	8.41
Below Miami River	103.3	181.7	174.5	262.3	130.4	22.2	20.0	16.5	18.3	9.06
Above Kentucky River	104.8	184.5	177.0	266.5	132.3	22.5	20.3	16.7	18.6	9.19
Below Kentucky River	108.4	196.2	185.2	278.9	137.5	23.9	21.1	17.9	20.1	10.4
At Louisville, Ky	108.0	221.0	192.0	297.0	147.0	28.8	23.1	18.3	20.9	7.51
Between sampling station 619 and Green River	113.3	232.0	201.0	311.5	154.3	30.2	24.2	19.2	21.9	7.97
At Evansville, Ind	122.0	260.0	217.0	341.0	185.0	37.7	26.3	22.4	32.8	19.9
Below Wabash River	133.8	290.5	269.5	408.8	210.0	46.6	30.8	26.4	37.3	23.7
Below Cumberland River	139.4	320.7	293.8	481.6	235.3	51.1	38.8	33.3	44.2	27.0
Below Tennessee River	162.8	383.0	347.7	607.6	279.3	68.2	58.0	50.0	60.1	39.3
Tributaries of Ohio River at their mouths										
Allegheny River	21.8	25.6	37.0	48.1	32.8	6.53	3.46	1.66	2.25	.84
Monongahela River	20.2	18.4	23.3	32.6	8.96	2.85	3.66	2.05	.96	.54
Beaver River	8.12	3.96	8.09	11.8	7.48	.85	.46	.36	.39	.24
Scioto River	5.05	14.2	19.1	17.2	6.95	1.00	.73	.96	.81	.49
Little Miami River	1.41	3.68	5.47	5.16	1.83	.18	.19	.55	.16	.24
Licking River	3.37	13.2	6.83	5.67	4.00	1.03	.11	.74	.23	.96
Miami River	3.65	8.72	14.5	14.3	4.43	1.24	1.00	1.27	.84	.65
Kentucky River	3.58	11.7	8.56	12.8	5.16	1.42	.84	1.15	1.53	1.22
Wabash River	11.8	30.5	52.5	67.8	25.0	8.87	4.53	4.02	4.54	3.82
Cumberland River	5.64	30.2	24.3	72.8	25.3	4.54	8.00	6.88	6.84	3.32
Tennessee River	23.4	62.3	53.9	126.0	44.0	17.1	19.2	16.7	15.9	12.3

[4] U. S. Geological Survey, Water Supply Paper 353, p. 257.

TABLE No. 15.—*Monthly mean discharge, in thousands of second-feet, of Ohio River at various points, and of certain tributaries (Oct. 1, 1914, to Dec. 31, 1915)*

	Discharge in thousands of second-feet														
	1914			1915											
	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December
Ohio River above Little Miami River	12.7	11.4	81.1	171.9	223.0	79.4	40.0	50.9	69.5	66.3	50.2	48.2	66.2	53.2	125.0
Ohio River above Licking River	13.3	11.6	82.1	174.5	234.4	79.9	40.2	51.5	70.8	67.8	52.2	50.8	67.5	54.2	132.2
Ohio River below Licking River	16.9	11.8	88.2	183.8	245.1	84.2	41.6	56.0	74.8	75.2	54.8	52.0	70.4	58.6	149.0
Ohio River below Miami River	18.1	12.6	90.4	187.7	262.9	87.2	43.5	58.8	79.0	86.5	60.2	58.4	75.0	62.0	155.6
Ohio River above Kentucky River	18.4	12.8	91.8	190.5	266.8	88.5	44.2	59.7	80.2	87.8	61.1	59.3	76.1	62.9	157.9
Ohio River below Kentucky River	22.2	13.1	99.1	203.7	279.1	95.5	46.9	63.4	85.6	97.2	65.4	61.1	81.4	70.0	191.9
Ohio River at Louisville, Ky	22.4	12.3	96.5	221.6	309.1	98.8	48.3	63.8	94.1	102.5	66.4	61.5	85.1	72.9	201.0
Tributaries of Ohio River															
Little Miami River at mouth	.62	.15	1.03	2.61	11.50	.63	.28	.61	1.31	1.54	2.06	2.60	1.33	.91	7.18
Licking River at mouth	3.60	.23	6.10	9.26	10.64	4.21	1.36	4.50	3.96	7.37	2.58	1.26	2.86	4.43	16.84
Miami River at mouth	1.24	.78	2.16	3.89	17.76	3.03	1.90	2.84	4.23	11.30	5.44	6.40	4.63	3.41	6.58
Kentucky River at mouth	3.85	.34	7.32	13.20	12.30	7.02	2.74	3.76	5.42	9.45	4.28	2.26	5.30	7.06	34.00

TABLE No. 16.—*Total monthly run-off, in inches depth, of Ohio River Basin above various points, and of certain tributary basins (Jan. 1 to Oct. 15, 1914)*

Basin	Area	Run-off in inches depth									
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct. 1–15
Ohio River above	*Sq. miles*										
Pittsburgh, Pa	19,020	2.35	2.31	3.47	4.65	2.56	0.55	0.33	0.23	0.20	0.05
East Liverpool, Ohio	23,440	2.40	2.25	3.48	4.68	2.58	.49	.30	.21	.19	.05
Wheeling, W. Va	24,980	2.17	2.36	3.30	4.86	2.57	.46	.31	.21	.20	.06
Point midway between Dam 14 and Muskingum River	26,700	2.00	2.33	3.17	4.76	2.46	.44	.30	.21	.20	.05
Little Kanawha River [1]	37,950	1.79	2.09	2.68	4.43	2.01	.36	.29	.21	.22	.04
Point between Hocking and Kanawha River	39,500	1.80	2.09	2.68	4.43	2.01	.38	.29	.21	.22	.04
Kanawha River [1]	52,690	1.88	2.31	2.54	3.92	1.88	.34	.33	.21	.24	.04
Scioto River [2]	62,320	1.71	2.34	2.50	3.82	1.89	.33	.31	.22	.25	.04
Little Miami River [2]	70,950	1.54	2.29	2.40	3.73	1.95	.31	.30	.23	.27	.06
Licking River [1]	76,320	1.51	2.36	2.42	3.63	1.90	.31	.29	.23	.26	.06
Miami River [1]	81,990	1.56	2.47	2.63	3.81	1.96	.32	.30	.25	.27	.06
Kentucky River [2]	83,130	1.45	2.31	2.45	3.57	1.83	.30	.28	.23	.25	.06
Louisville, Ky	91,190	1.36	2.52	2.43	3.64	1.86	.35	.29	.23	.26	.04
Evansville, Ind	107,100	1.31	2.53	2.34	3.56	1.99	.39	.28	.24	.34	.11
Cumberland River	144,000	1.08	2.10	2.16	3.06	1.68	.36	.24	.21	.29	.09
Tennessee River [2]	161,900	1.05	2.20	2.22	3.53	1.79	.38	.30	.25	.32	.10
Tennessee River [1]	202,700	.92	1.97	1.98	3.35	1.59	.38	.33	.29	.33	.11
Tributaries of Ohio River above mouths											
Allegheny River	11,680	2.21	2.35	3.76	4.73	3.33	.64	.35	.17	.22	.04
Monongahela River	7,339	3.17	2.61	3.66	4.95	1.41	.43	.58	.32	.14	.04
Beaver River	3,140	2.99	1.31	2.97	4.20	2.74	.32	.17	.13	.14	.04
Scioto River	6,410	.97	2.31	3.44	2.99	1.29	.17	.13	.17	.14	.04
Little Miami River	1,714	.97	2.28	3.76	3.42	1.26	.12	.13	.13	.10	.08
Licking River	3,636	1.07	3.78	2.17	1.74	1.27	.31	.03	.23	.07	.14
Miami River	5,410	.78	1.68	3.10	2.96	.95	.26	.21	.27	.17	.07
Kentucky River	6,912	.60	1.76	1.37	2.00	.86	.23	.14	.20	.25	.10
Wabash River	32,890	.42	.97	1.84	2.30	.88	.31	.16	.14	.08	.07
Cumberland River	17,860	.36	1.76	1.57	4.55	1.64	.28	.52	.44	.43	.11
Tennessee River	40,740	.66	1.59	1.52	3.46	1.24	.47	.54	.47	.44	.17

[1] Including designated tributary. [2] Excluding designated tributary.

TABLE No. 17.—*Total monthly run-off, in inches depth, of Ohio River Basin above various points and of certain tributary basins (Oct. 1, 1914, to Dec. 31, 1915)*

Basin	Area	Run-off in inches depth														
		1914			1915											
		October	November	December	January	February	March	April	May	June	July	August	September	October	November	December
	Sq. miles															
Ohio River above Little Miami River [1]	70,950	0.21	0.18	1.31	2.79	3.27	1.30	0.62	0.83	1.09	1.07	0.82	0.76	1.07	0.84	2.03
Ohio River above Licking River [2]	76,320	.26	.17	1.20	2.78	3.38	1.27	.61	.86	1.08	1.14	.83	.76	1.06	.89	2.25
Ohio River above Miami River [2]	81,990	.25	.17	1.15	2.64	3.34	1.22	.59	.83	1.07	1.22	.84	.79	1.06	.85	2.19
Ohio River above Kentucky River [2]	90,040	.28	.16	1.26	2.60	3.23	1.21	.58	.81	1.06	1.23	.84	.76	1.04	.87	2.46
Ohio River above Louisville, Ky	91,190	.28	.15	1.34	2.80	3.53	1.26	.59	.81	1.15	1.29	.84	.75	1.07	.89	2.54
Tributaries of Ohio River																
Little Miami River above mouth	1,714	.43	.10	.71	1.79	7.39	.43	.19	.42	.87	1.06	1.42	1.73	.91	.60	4.93
Licking River above mouth	3,636	1.14	.07	1.94	2.94	3.15	1.34	.42	1.43	1.22	2.34	.82	.39	.91	1.36	5.34
Miami River above mouth	5,410	.26	.16	.46	.83	3.56	.65	.39	.61	.87	2.42	1.16	1.33	.99	.70	1.41
Kentucky River above mouth	6,912	.64	.06	1.22	2.19	1.92	1.16	.44	.63	.88	1.58	.71	.36	.88	1.14	5.67

[1] Excluding designated tributary. [2] Including designated tributary.

Proportionate contributions of various tributaries to discharge of main stream.—The estimated contribution of each tributary of known discharge to the volume of water passing Pittsburgh, Cincinnati, and Louisville, respectively, in each month of the period January 1 to October 15, 1914, is shown in Table No. 18, while Table No. 19 gives similar estimates for the water passing Cincinnati and Louisville from October 1, 1914, to December 31, 1915.

TABLE No. 18.—*Percentage of total discharge of Ohio River at various points contributed by various subdivisions of the watershed (Jan. 1 to Oct. 15, 1914)*

[Monthly mean values]

	Drainage area	Percentage of total discharge contributed									
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct. 1–15
	Sq. miles										
Ohio River at Pittsburgh	19,020	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Allegheny River	11,680	56.2	60.7	64.7	60.7	77.8	69.7	64.3	44.5	66.8	50.4
Monongahela River	7,339	43.8	39.3	35.3	39.3	22.2	30.3	35.7	55.5	33.2	49.6
Ohio River at Cincinnati	76,320	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Allegheny River	11,680	21.9	14.8	23.1	19.4	26.0	31.1	18.2	11.0	12.9	10.0
Monongahela River	7,339	20.3	10.6	14.6	13.2	7.1	13.6	19.8	13.5	5.5	6.4
Beaver River	3,140	8.2	2.3	5.1	4.8	5.9	4.1	2.4	2.4	2.2	2.9
Scioto River	6,410	5.1	8.2	12.0	6.9	5.5	4.8	3.8	6.3	4.6	5.8
Other drainage areas above Little Miami River	42,381	39.7	54.4	37.5	51.3	50.8	40.6	54.2	58.3	72.6	60.6
Little Miami River	1,714	1.4	2.1	3.4	2.1	1.5	.9	1.0	3.6	.9	2.9
Licking River	3,636	3.4	7.6	4.3	2.3	3.2	4.9	.6	4.9	1.3	11.4
Ohio River at Louisville	91,190	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Allegheny River	11,680	20.2	11.6	19.3	16.5	22.3	22.7	15.0	9.1	10.8	11.2
Monongahela River	7,339	18.7	8.3	12.2	11.0	6.1	9.9	15.8	11.2	4.6	7.2
Beaver River	3,140	7.5	1.8	4.2	4.0	5.1	3.0	2.0	2.0	1.9	3.2
Scioto River	6,410	4.7	6.4	10.0	5.8	4.7	3.5	3.2	5.2	3.9	6.5
Other drainage areas above Little Miami River	42,381	36.8	42.4	31.2	42.6	43.3	29.4	44.9	49.0	64.7	28.1
Little Miami River	1,714	1.3	1.7	2.8	1.7	1.2	.6	.8	3.0	.8	2.8
Licking River	3,636	3.1	6.0	3.6	1.9	2.7	3.6	.5	4.0	1.1	16.1
Total above Miami River	76,580	92.3	78.2	83.3	83.5	85.4	72.7	82.2	83.5	87.8	75.1
Miami River	5,410	3.4	4.0	7.6	4.8	3.0	4.3	4.3	6.9	4.0	5.5
Kentucky River	6,910	3.3	5.3	4.5	4.3	3.5	4.9	3.6	6.3	7.3	17.2
Not accounted for	2,550	1.0	12.5	4.6	7.4	8.1	18.1	9.9	3.3	.9	2.2

TABLE NO. 19.—*Percentage of total discharge of the Ohio River at designated points, between Cincinnati and Louisville, contributed by various subdivisions of the watershed (Oct. 1, 1914, to Dec. 31, 1915)*

[Monthly mean values].

	Drainage area	Percentage of total discharge contributed														
		1914			1915											
		October	November	December	January	February	March	April	May	June	July	August	September	October	November	December
	Sq. miles															
Ohio River at Cincinnati	76, 320	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0
All drainage areas above Little Miami River	70, 950	75. 0	96. 8	91. 8	93. 5	91. 0	94. 2	96. 0	90. 9	92. 9	88. 2	91. 5	92. 6	94. 0	90. 8	83. 9
Little Miami River	1, 714	3. 7	1. 3	1. 3	1. 4	4. 7	. 8	. 7	1. 1	1. 8	2. 0	3. 8	5. 0	1. 9	1. 6	4. 8
Licking River	3, 636	21. 3	1. 9	6. 9	5. 1	4. 3	5. 0	3. 3	8. 0	5. 3	9. 8	4. 7	2. 4	4. 1	7. 6	11. 3
Ohio River at Louisville	91, 190	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0
All drainage areas above Little Miami River	70, 950	56. 7	[1] 84. 5	[1] 80. 0	77. 4	72. 3	80. 3	82. 7	79. 7	73. 9	64. 6	75. 4	78. 7	77. 8	73. 5	65. 4
Little Miami River	1, 714	2. 8	1. 2	1. 1	1. 2	3. 7	. 6	. 6	1. 0	1. 4	1. 5	3. 1	4. 2	1. 6	1. 3	3. 6
Licking River	3, 636	16. 1	1. 9	6. 3	4. 2	3. 4	4. 3	2. 8	7. 1	4. 2	7. 2	3. 9	2. 1	3. 4	6. 1	8. 4
Total above Miami River	76, 580	75. 6	87. 6	87. 4	82. 8	79. 4	85. 2	86. 1	87. 8	79. 5	73. 3	82. 4	85. 0	82. 8	80. 9	77. 4
Miami River	5, 410	5. 5	6. 4	2. 2	1. 8	5. 7	3. 1	3. 9	4. 4	4. 5	11. 0	8. 2	10. 5	5. 4	4. 7	3. 3
Kentucky River	6, 912	17. 2	2. 8	7. 6	6. 0	4. 0	7. 1	5. 7	5. 9	5. 8	9. 2	6. 5	3. 7	6. 2	9. 7	16. 9
Not accounted for	2, 548	1. 7	[1] 3. 2	[1] 2. 8	9. 4	10. 9	4. 6	4. 3	1. 9	10. 2	6. 5	2. 9	. 8	5. 6	4. 7	2. 4

[1] Estimated, since indicated discharge figures for Cincinnati plus intermediate tributaries exceeds indicated discharge at Louisville.

The relative influence of various tributaries upon the discharge of the main stream, as shown in these tables, is, in general, closely proportional to their respective drainage areas, though this relationship is modified at times by variations in the run-off from different areas. Thus, from month to month the proportionate contributions of given tributaries to the discharge of the Ohio vary considerably; and, for shorter periods of a few days, the influence of a single tributary or group of tributaries may be greatly exaggerated. For example, a sharp rise in the river early in February, 1914, was caused largely by a freshet in the Allegheny Basin, while the next rise of consequence, in the latter part of the same month, was due to unusual run-off from the Monongahela and probably other tributaries draining the West Virginia-Kentucky region. Most of the major freshets of the Ohio result from heavy run-off over wide areas, though a few floods, such as the disastrous one of 1913, have been caused by excessive precipitation over rather limited areas.

By far the largest tributaries of the Ohio are the Cumberland and Tennessee, the combined discharge of which, during short periods, sometimes exceeds that of the Ohio above them. Thus, in July, 1914, due to a temporary rise of these two streams, their discharge was for a few days over twice that of the Ohio at Evansville.

ESTIMATES OF VELOCITY

Methods employed.—The problem of estimating velocities in a stream of such size and length as the Ohio River presents many difficulties; and various methods were carefully considered before the one finally applied was adopted. Direct measurements of velocity by means of floats were made in several stretches of the river, partly as a test of the practicability of this method and partly as a check upon the results obtained by other methods. It was, however, clearly evident that float measurements sufficient to afford satisfactory estimates applicable to the whole length of the river through a wide range of gage heights, would require many months of laborious field work at great expense, and that this method was unsatisfactory in other respects.

In the absence of other more suitable methods, estimates made by applying modifications of the well-known Chezy formula would have been applicable, since the hydraulic radius and slope of the Ohio in various stretches are fairly well determined, and proper values could be assumed for obtaining the Kutter or Hazen-Williams coefficients.

However, it was not necessary to resort to the Chezy formula, since detailed topographic maps of the river bed, from which any desired cross section could be plotted, furnished the data required for application of the formula:

$$V=\frac{Q}{A}, \text{ in which}$$

V = Velocity of flow, in feet per second;
Q = Quantity of discharge, in cubic feet per second;
A = Area of cross-section of flow, in square feet.

Given the discharge of the river at two successive cross sections, the application of this formula requires only a determination of the cross-sectional area of flow ("A"). This is quite simple in the case of water flowing in a conduit of uniform and regular cross section; but presents some complications in the case of a stream like the Ohio, where the natural channel is constantly changing in contour and is modified at times by the raising of dams. The method described below, though based upon simple and well-known principles, has not previously been applied so far as known to us to estimating velocities in such a stream as the Ohio.

As the first step in the procedure, the river was divided into a series of 72 consecutive prisms, extending from Pittsburgh to the lowest sampling station below Paducah, 933 miles from Pittsburgh. For obvious reasons, the limits of a prism were taken at:

(*a*) The mouth of an important tributary, introducing an abrupt change in the discharge factor.

(*b*) A dam, making an abrupt change in cross-sectional area of flow.

(*c*) A sampling station, as a point to and from which times of passage must be determined.

In calculating the mean cross-sectional areas of flow of each prism, a number of cross sections, sufficing to fairly represent all important changes in the channel, were selected from the topographic maps[5] and plotted upon cross-section paper. The cross-sectional areas lying below successive elevations of water surface at 5-foot intervals were then measured by planimeter, and from these measurements mass-area curves were drawn, showing, for each section, the relation between elevation of water surface and cross-sectional area of flow. From these curves tables were made, showing for each prism the areas of all sections below each elevation. A weighted average cross-sectional area for each prism below each given elevation was then obtained, the area at each cross section being weighted by the distance (in miles) between it and the section next above. From the weighted average areas a single mass-area curve was then constructed for each prism giving the mean cross-sectional area of the whole prism corresponding to varying elevations of water surface.

The mean cross-sectional area of flow in the prism at each elevation of the water surface could, however, be obtained from such a curve only in case the water surface throughout the prism were level, a condition which exists only in pools. It was necessary, therefore, to correct the areas for slope of water surface, determined by a study of the differences in elevation at successive gages at different river stages. Comparing each gage with the one next above and the one next below, curves were constructed showing the correlation between

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[5] The topographic maps used were those on file in the offices of the district engineers of the U. S. Army Engineer Corps at Cincinnati and Louisville, which were made available through the courtesy of the officers in charge.

simultaneous readings at each pair of gages. The elevation of the zero point on each gage above a common datum[6] being known, the relation between gages was readily translated from terms of gage heights into terms of water-surface elevation above this common datum, and profiles of the water surface at different river stages plotted. In plotting such profiles, the assumption was made that the slope between two successive gages is a straight line, an assumption which, though not literally true, is a close enough approximation for all practical purposes, since deviations above and below a straight line in the actual profile are probably compensating, convexities of the profile during rising stages tending to balance concavities during falling stages.

From these profiles, indicating directly the mean elevation of water surface in each prism at various readings of the reference gage, corrected mass-area curves were drawn, showing the mean cross-sectional areas of flow in each prism for various gage heights. The discharge and mean cross-sectional area of flow corresponding to the observed gage height in each prism being known, the corresponding mean velocity of flow could then be calculated from the relation, $V=\frac{Q}{A}$, previously noted. Then from mean velocity of flow within a prism and the distance between its terminals the corresponding time of passage of water between the upper and lower ends of the prism was computed, in terms of hours or days, and times of passage between any two points on the river determined by summation or prorating of these intervals. For convenience in application, curves were drawn, showing directly, for each prism, the relation between gage height at the reference gage, mean velocity of flow, and time of passage.

In estimating the cross-sectional area of a prism consisting wholly or chiefly of a pool located above and controlled by a dam, the procedure differs from that described, since the water surface during pool stages, that is, when the dam is raised, is practically level and is so considered. Also, in such case, the reference gage must be located in the pool itself. Hence, in those prisms terminating in dams it has been necessary in actual calculations to differentiate between periods of "open channel," when the dams are not in use, and "pool stages," when the wickets of the dams are raised, in accordance with records of actual maneuvers of each dam during 1914 and 1915, as furnished by the several district engineer officers in charge of these dams.

As to the precision of the final estimates, it is extremely difficult to form a judgment of their probable error. Estimates of velocity are derived from two factors, independently determined, namely, discharge and cross-sectional area of flow. As has already been pointed out, it is believed that estimates of monthly mean discharge

[6] Mean sea level, Sandy Hook, N. J.

are subject to a probable error not exceeding about 10 per cent. It is difficult, without an extensive analysis of the base data, to judge whether the error in estimates of cross-sectional areas of flow is

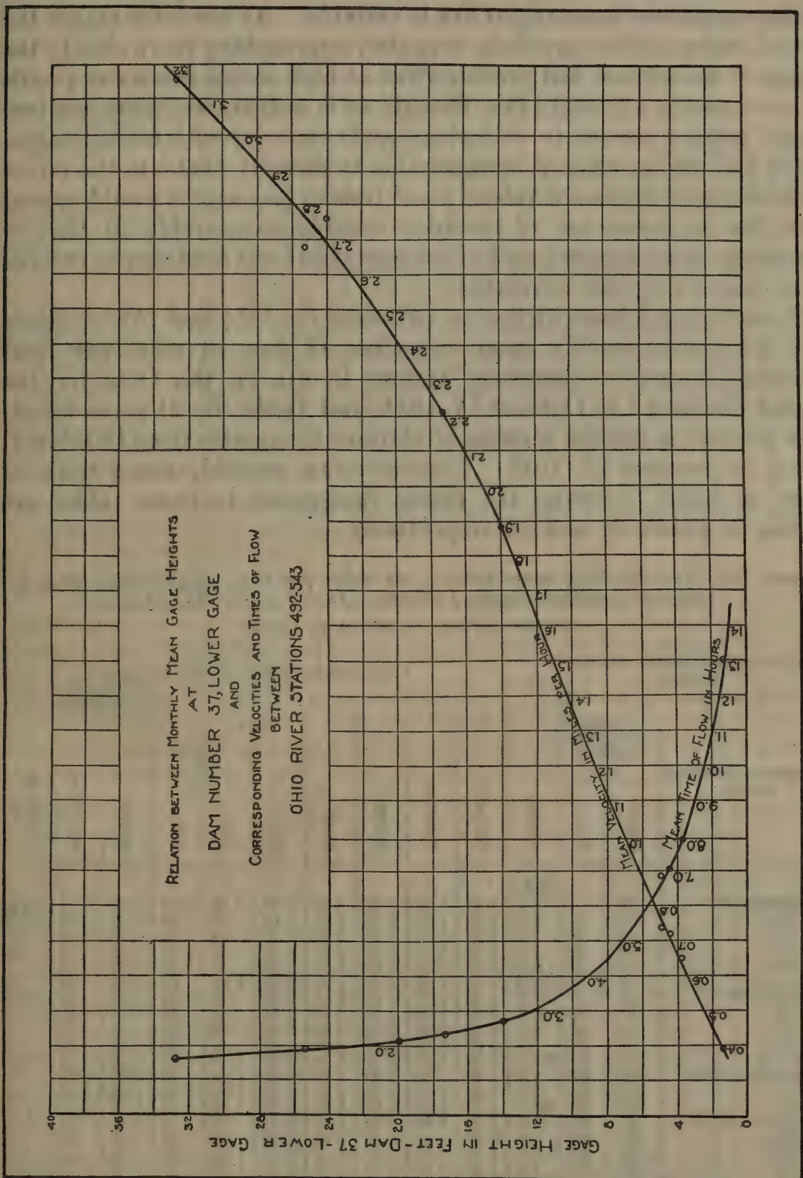

FIG. 8

generally greater or less than this; but careful study of channel sections taken at short intervals shows a rather surprising uniformity in areas of flow, notwithstanding changes in the shape of the channel;

and in shorter prisms the deviation of individual cross-section areas from the mean is surprisingly small, all of which indicates that estimates of mean cross-sectional areas are fairly precise.

The error involved in the assumption that the slope of the water surface in prisms is a straight line is variable. At low river stages the actual water surface profile is irregular, approaching more closely the shape of the stream bed profile, while at high stages the water profile is more nearly a straight line, though, as is well known, there is a tendency toward convexity with rising and concavity with falling stages.

On the whole, while it is impossible to directly evaluate the errors in final computations of velocity and time of passage, it would appear that the estimates are of precision roughly comparable to that of discharge measurements and of the analytical and field survey records with which they are correlated.

Velocities and times of flow as estimated for 1914 and 1915.—Table No. 20 gives monthly mean velocities of flow in miles per hour between successive sampling stations in use on the Ohio for the period January 1 to October 15, 1914; and Table No. 21 gives velocities between a smaller number of stations by months from October 1, 1914, to January 31, 1915. Corresponding monthly mean times of flow, in hours, between the points designated in these tables are shown in Tables 22 and 23, respectively.

TABLE No. 20.—*Monthly mean velocity, in miles per hour, of the Ohio River between consecutive sampling stations (Jan. 1 to Oct. 15, 1914)*

[One mile per hour = 1.467 feet per second]

River stretch to which velocity applies				Mean velocity of flow in miles per hour									
Laboratory covering stretch	Limits (sampling stations)		Length	1914									
	From—	To—		January	February	March	April	May	June	July	August	September	October 1–15
			Miles										
Pittsburgh, Pa	0	3	3.1	1.48	1.63	2.07	2.38	1.48	0.34	0.19	0.13	0.12	0.06
Do	3	11	8.6	1.76	1.87	2.33	2.61	1.69	.34	.20	.13	.12	.06
Do	11	19	7.3	1.59	1.70	2.03	2.28	1.70	.40	.22	.15	.13	.07
Do	19	23	4.0	2.23	2.36	2.67	2.67	2.23	.52	.28	.19	.18	.09
Do	23	29	6.2	2.48	2.58	2.95	3.10	2.58	.61	.34	.23	.22	.11
None	29	65	36.0	2.90	2.88	3.43	3.53	2.90	1.02	.67	.40	.30	.17
Wheeling, W. Va	65	77	11.9	2.29	2.59	2.84	3.13	2.48	.48	.30	.21	.21	.10
Do	77	88	10.8	2.20	2.70	2.77	3.00	2.51	.69	.42	.27	.27	.15
Do	88	97	8.7	2.18	2.64	2.72	2.90	2.42	.63	.36	.25	.25	.14
Do	97	104	7.0	1.89	2.26	2.50	2.92	1.95	.54	.32	.22	.22	.12
None	104	349	245.0	2.39	2.42	2.82	3.13	2.54	1.01	.80	.62	.65	.35
Portsmouth, Ohio	349	355	6.0	2.22	2.50	2.40	2.73	2.31	1.28	1.25	1.07	1.15	.57
Do	355	358	2.8	2.34	2.80	2.80	2.80	2.34	1.56	1.56	1.48	1.56	1.08
None	358	461	103.2	2.59	2.84	2.93	3.01	2.69	1.63	1.60	1.37	1.51	1.00
Cincinnati, Ohio	461	475	13.6	2.30	2.89	2.78	3.16	2.52	.85	.73	.58	.67	.31
Do	475	482	7.3	2.03	2.56	2.48	2.92	2.28	.63	.54	.44	.50	.25
Do	482	488	5.9	2.18	2.68	2.68	3.10	2.46	1.00	.95	.84	.91	.59
Do	488	492	4.2	2.47	3.00	3.00	3.23	2.80	1.31	1.27	1.20	1.20	.91
Do	492	543	50.9	2.24	2.68	2.76	3.16	2.40	.83	.74	.65	.72	.39
None	543	598	54.5	1.69	2.38	2.47	3.07	2.08	.65	.52	.42	.48	.18
Louisville, Ky	598	611	13.2	1.61	2.54	2.32	2.81	2.00	.58	.46	.38	.43	.17
Do	611	619	7.7	2.20	2.85	2.75	3.08	2.48	1.17	.99	.85	.94	.46
None	619	904	285.0	1.99	2.62	2.51	2.91	2.16	.95	.80	.71	.78	.41
Paducah, Ky	904	920	17.5	1.99	2.46	2.27	2.50	1.99	1.00	.85	.87	.97	.81
Do	920	926	5.3	1.47	2.12	2.02	2.52	1.71	.83	.78	.82	.80	.70
Do	926	933	7.6	1.73	2.54	2.30	2.92	1.95	.93	.88	.88	.90	.74

TABLE No. 21.—*Monthly mean velocity, in miles per hour, of Ohio River between designated points, Pittsburgh to Cincinnati, and between consecutive sampling stations, Cincinnati to Louisville (Oct. 1, 1914, to Dec. 31, 1915)*

River stretch to which velocity applies				Mean velocity of flow in miles per hour														
Laboratory covering stretch	Limits (sampling stations) From—	Limits (sampling stations) To—	Length	1914 October	1914 November	1914 December	1915 January	1915 February	1915 March	1915 April	1915 May	1915 June	1915 July	1915 August	1915 September	1915 October	1915 November	1915 December
			Miles															
None	0	29	29.3	0.11	0.29	1.62	2.57	2.64	1.53	1.18	1.50	1.25	1.43	1.36	0.73	1.36	1.38	2.26
Do	29	65	36.0	.15	.31	2.52	3.60	3.60	2.38	1.97	2.35	2.06	2.29	2.20	1.45	2.20	2.22	3.30
Do	65	104	38.4	.11	.26	2.02	2.85	3.05	1.24	.96	1.26	1.05	1.24	1.04	.62	1.11	1.01	2.30
Do	104	349	245.0	.56	.56	2.19	3.06	3.12	2.20	1.51	1.73	1.92	1.95	1.66	1.59	1.89	1.70	2.60
Do	349	358	8.8	1.13	1.13	2.20	2.59	2.75	2.20	1.84	1.96	2.20	2.20	1.96	1.92	2.05	1.96	2.38
Do	358	461	103.2	1.20	1.17	2.52	2.93	3.00	2.50	2.13	2.24	2.22	2.22	2.24	2.14	2.35	2.20	2.74
Cincinnati, Ohio	461	475	13.6	.61	.53	2.12	2.96	3.16	2.12	1.48	1.68	1.97	2.00	1.72	1.56	1.86	1.64	2.62
Do	475	482	7.3	.43	.37	1.83	2.61	2.92	1.87	1.18	1.40	1.70	1.74	1.43	1.28	1.59	1.35	2.38
Do	482	488	5.9	.84	.76	2.04	2.81	3.11	2.04	1.44	1.64	1.90	1.90	1.69	1.55	1.74	1.64	2.55
Do	488	492	4.2	1.17	1.05	2.34	3.00	3.23	2.34	1.75	1.91	2.21	2.21	1.91	1.83	2.10	1.91	2.90
Do	492	543	50.9	.65	.56	2.00	2.80	3.12	2.03	1.34	1.58	1.89	1.91	1.62	1.45	1.79	1.54	2.51
None	543	598	54.5	.43	.34	1.47	2.72	3.03	1.51	.88	1.04	1.32	1.37	1.07	.94	1.21	1.01	2.27
Louisville, Ky	598	611	13.2	.41	.27	1.53	2.54	2.80	1.55	.76	.96	1.47	----	----	----	----	----	----
Do	611	619	7.7	.92	.62	2.08	2.96	3.21	2.14	1.54	1.75	2.08	----	----	----	----	----	----

TABLE No. 22.—*Monthly mean time of flow, in hours, of the Ohio River between consecutive sampling stations, with group summaries for designated stretches (Jan. 1 to Oct. 15, 1914)*

River stretches to which time of flow applies				Mean time of flow, in hours									
Laboratory covering stretch	Limits (sampling stations) From—	Limits (sampling stations) To—	Length	January	February	March	April	May	June	July	August	September	October 1–15
			Miles										
Pittsburgh, Pa	0	3	3.1	2.1	1.9	1.5	1.3	2.1	9.1	16.3	24.0	25.3	50.6
Do	3	11	8.6	4.9	4.6	3.7	3.3	5.1	25.6	43.5	65.6	73.4	148.6
Do	11	19	7.3	4.6	4.3	3.6	3.2	4.3	18.4	32.6	47.6	55.1	104.9
Do	19	23	4.0	1.8	1.7	1.5	1.5	1.8	7.7	14.4	21.0	22.6	45.3
Do	23	29	6.2	2.5	2.4	2.1	2.0	2.4	10.2	18.0	26.4	28.5	54.6
Do	0	29	29.3	15.9	14.9	12.4	11.3	15.7	71.0	124.8	184.6	204.9	404.0
None	29	65	36.0	12.4	12.5	10.5	10.2	12.4	35.4	54.0	91.0	118.8	217.8
Wheeling, W. Va	65	77	11.9	5.2	4.6	4.2	3.8	4.8	24.6	41.6	59.2	61.0	120.3
Do	77	88	10.8	4.9	4.0	3.9	3.6	4.3	15.6	24.1	36.1	36.1	65.5
Do	88	97	8.7	4.0	3.3	3.2	3.0	3.6	13.9	24.1	34.7	35.5	63.8
Do	97	104	7.0	3.7	3.1	2.8	2.4	3.6	13.0	21.9	32.2	32.2	57.2
Do	65	104	38.4	17.8	15.0	14.1	12.8	16.3	67.1	111.7	162.2	164.8	306.2
None	104	349	245.0	102.7	93.6	87.0	78.2	96.6	241.9	306.7	398.2	378.0	710.3
Portsmouth, Ohio	349	355	6.0	2.7	2.4	2.5	2.2	2.6	4.7	4.8	5.6	5.2	10.6
Do	355	358	2.8	1.2	1.0	1.0	1.0	1.2	1.8	1.8	1.9	1.8	2.6
Do	349	358	8.8	3.9	3.4	3.5	3.2	3.8	6.5	6.6	7.5	7.0	13.2
None	358	461	103.2	39.9	36.3	35.2	34.3	38.4	63.4	64.3	75.5	68.4	103.6
Cincinnati, Ohio	461	475	13.6	5.9	4.7	4.9	4.3	5.4	16.0	18.7	23.5	20.2	43.7
Do	475	482	7.3	3.6	2.8	3.0	2.5	3.2	11.6	13.5	16.5	14.7	28.8
Do	482	488	5.9	2.7	2.2	2.2	1.9	2.4	5.9	6.2	7.0	6.5	10.1
Do	488	492	4.2	1.7	1.4	1.4	1.3	1.5	3.2	3.3	3.5	3.5	4.6
Do	461	492	31.0	13.9	11.1	11.5	10.0	12.5	36.7	41.7	50.5	44.9	87.2
Do	492	543	50.9	23.0	19.0	18.4	16.1	21.2	61.0	68.7	78.9	70.8	130.2
None	543	598	54.5	32.2	22.9	22.2	17.8	26.4	84.3	105.4	129.2	114.5	297.0
Do	492	598	105.4	55.2	41.9	40.6	33.9	47.6	145.3	174.1	208.1	185.3	427.2
Louisville, Ky	598	611	13.2	8.2	5.2	5.7	4.7	6.6	22.8	28.7	34.5	30.6	79.9
Do	611	619	7.7	3.5	2.7	2.8	2.5	3.1	6.6	7.8	9.1	8.2	16.9
Do	598	619	20.9	11.7	7.7	8.5	7.2	9.7	29.4	36.5	43.6	38.8	96.8
None	619	904	285.0	143.1	108.8	113.6	98.1	132.0	301.4	355.3	401.7	366.0	694.1
Paducah, Ky	904	920	17.5	8.8	7.1	7.7	7.0	8.8	17.4	20.6	20.0	18.0	21.7
Do	920	926	5.3	3.6	2.5	2.6	2.1	3.1	6.4	6.8	6.5	6.6	7.6
Do	926	933	7.6	4.4	3.0	3.3	2.6	3.9	8.2	8.6	8.6	8.4	10.3
Do	904	933	30.4	16.8	12.6	13.6	11.7	15.8	32.0	36.0	35.1	33.0	39.6

TABLE No. 23.—*Monthly mean time of flow, in hours, of the Ohio River between designated points, Pittsburgh to Cincinnati, and between consecutive sampling stations, Cincinnati to Louisville (Oct. 1, 1914, to Dec. 31, 1915)*

River stretch to which time of flow applies				Mean time of flow, in hours														
				1914			1915											
Laboratory covering stretch	Limits (sampling stations)																	
	From—	To—	Length.	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December
			Miles															
None	0	29	29.3	260.3	102.0	18.1	11.4	11.1	19.2	24.9	19.6	23.4	20.5	21.5	40.3	21.5	21.2	13.0
Do	29	65	36.0	240.0	115.0	14.3	10.0	10.0	15.1	18.3	15.3	17.5	15.7	16.4	24.8	16.4	16.2	10.9
Do	65	104	38.4	333.4	145.1	19.0	13.5	12.6	31.0	40.2	30.5	36.5	31.0	35.9	61.8	34.5	38.0	16.7
Do	104	349	245.0	434.0	434.0	112.0	80.0	78.5	111.5	162.5	142.0	128.0	125.5	147.5	154.0	129.5	144.0	94.0
Do	349	358	8.8	7.8	7.8	4.0	3.4	3.2	4.0	4.8	4.5	4.2	4.2	4.5	4.6	4.3	4.5	3.7
Do	358	461	103.2	85.9	88.7	41.0	35.2	34.4	41.4	48.4	46.1	46.5	46.4	46.0	48.3	44.0	46.9	37.7
Cincinnati, Ohio	461	475	13.6	22.3	25.8	6.4	4.6	4.3	6.4	9.2	8.1	6.9	6.8	7.9	8.7	7.3	8.3	5.2
Do	475	482	7.3	16.8	19.9	4.0	2.8	2.5	3.9	6.2	5.2	4.3	4.2	5.1	5.7	4.6	5.4	3.1
Do	482	488	5.9	7.0	7.8	2.9	2.1	1.9	2.9	4.1	3.6	3.1	3.1	3.5	3.8	3.4	3.6	2.8
Do	488	492	4.2	3.6	4.0	1.8	1.4	1.3	1.8	2.4	2.2	1.9	1.9	2.2	2.3	2.0	2.2	1.5
Do	492	543	50.9	78.6	91.6	25.4	18.2	16.3	25.1	37.9	32.2	27.0	26.7	31.4	35.2	28.4	33.0	20.3
None	543	598	54.5	128.0	159.0	37.0	20.0	18.0	36.2	61.9	52.5	41.2	39.8	51.0	57.9	45.0	54.1	24.0
Louisville, Ky	598	611	13.2	32.0	49.0	8.6	5.2	4.7	8.5	17.3	13.7	9.0	-----	-----	-----	-----	-----	----
Do	611	619	7.7	8.4	12.5	3.7	2.6	2.4	3.6	5.0	4.4	3.7	-----	-----	-----	-----	-----	----

It is to be noted, in connection with these tables, that summation of the mean times of flow between successive stretches does not necessarily give the correct actual time of flow between two such distant points as the origin and the mouth of the Ohio. It gives only the time which would have been required had the mean flow conditions existing in each stretch remained constant during the whole period required for a body of water to pass through each stretch in succession; and actually such constancy of flow is not realized for any considerable period in the Ohio River. In periods when the river is at a fairly uniform high stage, so that the entire time of flow from origin to mouth would be short, the summation of mean time intervals given in Table No. 24 may approximate the times actually required for passage of water from Pittsburgh to the successive points indicated. But where the river stage is progressively falling, the actual time will be longer than thus indicated; and with either a progressive or a sudden rise it will be shortened. For example, it is likely that water leaving Pittsburgh in June, July, and August, actually required as long to arrive at the mouth of the Ohio as indicated by these tables, that is from 40 to 70 days, since the river during the whole of the period from June to October 15 was at a low and generally falling stage. But according to summation of time intervals the water leaving Pittsburgh in the last part of October would have required

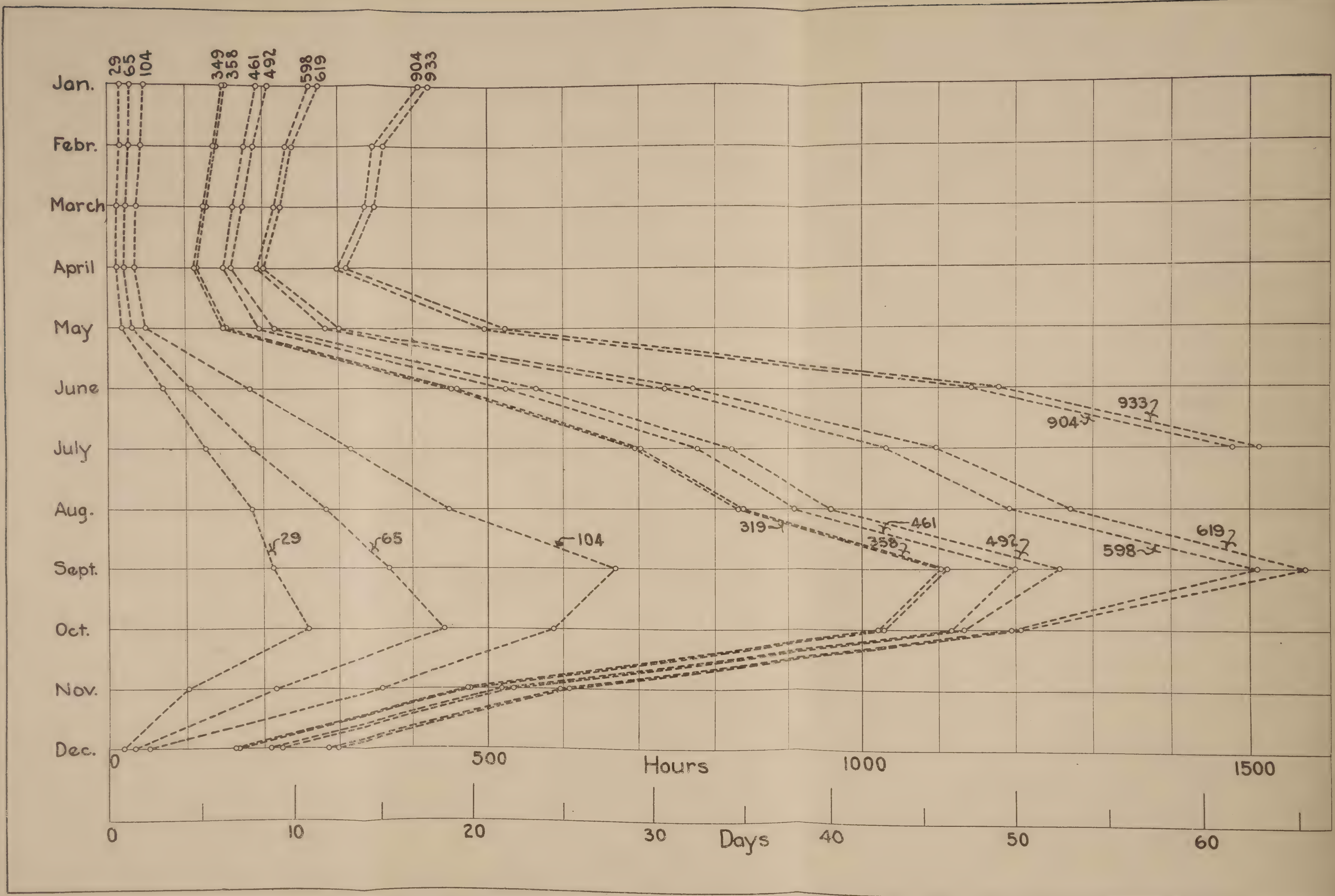

Fig. 9.—Time required for water leaving Pittsburgh on the 15th of each month to reach successive sampling stations on the Ohio River

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over 3,000 hours (125 days) to reach station 933, arriving there about February 1. Long before this, rising river stages had swept this water forward through the stream, greatly reducing this calculated time interval. An attempt has been made to correct the data used in Figure 9, by taking into account the successive changes in velocity which would actually affect the passage downstream of water leaving Pittsburgh on the fifteenth of each month; and this figure accordingly shows actual time intervals between distant points somewhat more correctly than they are given in Table 24. It will be readily apparent, however, that estimates applied to long stretches, where the time intervals extend over many days are at best more or less hypothetical. In the shorter stretches the actual times of flow presumably correspond more closely to the estimates, though varying more or less widely from day to day within such a period as a month.

TABLE No. 24.—*Monthly mean time of flow, in days, from confluence at Pittsburgh to each sampling station (Jan. 1 to Oct. 15, 1914)*

To sampling station—	Distance	Mean time of flow in days									
		January	February	March	April	May	June	July	August	September	October 1–15
	Miles										
3	3.1	0.09	0.09	0.06	0.05	0.09	0.38	0.68	1.00	1.05	2.11
11	11.8	.29	.28	.21	.19	.30	1.45	2.49	3.73	4.11	8.34
19	19.1	.48	.46	.36	.32	.48	2.22	3.85	5.71	6.41	12.71
23	23.1	.56	.53	.42	.38	.56	2.54	4.45	6.59	7.35	14.60
29	29.3	.66	.63	.51	.46	.66	2.96	5.20	7.69	8.34	16.88
65	65.3	1.18	1.15	.95	.89	1.18	4.44	7.45	11.49	13.49	25.95
77	77.2	1.40	1.34	1.13	1.05	1.38	5.46	9.09	13.81	15.88	30.69
88	88.0	1.60	1.51	1.29	1.20	1.56	6.11	10.20	15.47	17.54	33.70
97	96.7	1.77	1.65	1.42	1.32	1.71	6.69	11.20	16.98	19.02	36.36
104	103.7	1.92	1.78	1.54	1.42	1.86	7.23	12.11	18.26	20.36	38.74
349	349.4	6.20	5.68	5.17	4.68	5.89	17.32	24.90	34.88	36.12	68.38
355	355.4	6.31	5.78	5.27	4.77	6.00	17.52	25.10	35.11	36.34	68.82
358	358.2	6.36	5.82	5.31	4.81	6.05	17.60	25.18	35.19	36.42	68.93
461	461.4	8.02	7.33	6.78	6.24	7.65	20.24	27.86	38.34	39.27	73.25
475	475.0	8.27	7.53	6.98	6.42	7.87	20.91	28.64	39.32	40.11	75.07
482	482.3	8.42	7.69	7.14	6.52	8.00	21.39	29.20	40.01	40.72	76.27
488	488.2	8.53	7.78	7.23	6.60	8.10	21.64	29.46	40.30	40.99	76.69
492	492.4	8.60	7.84	7.29	6.65	8.16	21.77	29.60	40.31	41.14	76.88
543	543.0	9.56	8.63	8.06	7.32	9.04	24.31	32.46	43.60	44.09	82.30
598	597.8	10.90	9.58	8.98	8.06	10.14	27.83	36.86	48.98	48.86	94.68
611	611.0	11.24	9.80	9.22	8.26	10.42	28.78	38.06	50.42	50.14	98.01
619	618.7	11.39	9.91	9.34	8.36	10.55	29.06	38.38	50.80	50.48	98.71
904	903.7	17.35	14.44	14.07	12.45	16.05	41.62	53.19	67.54	65.73	127.71
920	921.2	17.72	14.74	14.39	12.74	16.42	42.34	54.05	68.37	66.48	128.61
926	926.5	17.87	14.84	14.50	12.83	16.55	42.61	54.33	68.64	66.76	128.93
933	934.1	18.09	14.96	14.64	12.94	16.71	42.95	54.69	69.00	67.11	129.36

COMPARISON OF HYDROGRAPHIC CONDITIONS IN THE OHIO BASIN DURING THE YEARS 1914 AND 1915 WITH NORMAL CONDITIONS

Rainfall.—The records of rainfall upon the Ohio watershed and its main subdivisions during each month of the years 1914 and 1915 are summarized in Table No. 25, which also shows the average rainfall in corresponding areas for the years of record prior to 1914. These figures are obtained, in each area, by averaging observations at all stations within the area, which may give excessive weight to observations in those regions where observation stations are most numerous.

For the years prior to 1914, the periods of record at different stations are unequal, and the averages are therefore not entirely comparable; but they probably are sufficiently representative for rough comparisons.

During 1914 the rainfall was approximately normal from January to April, but was generally below the average from May to November; so that for the entire year there was a deficiency upon the watershed as a whole and in each subdivision. In 1915 there was a very considerable and unusual deficiency during February, March, and April, but this was counterbalanced by high rainfall during the remaining months, so that in almost all areas the annual total was in excess of the average.

TABLE No. 25.—*Monthly and annual rainfall on Ohio watershed and on various tributaries thereof: Average for period of record to 1913, and actual for years 1914 and 1915.*

Drainage area	Area		Rainfall, inches depth: Monthly: January	February	March	April	May	June	July	August	September	October	November	December	Total yearly
OHIO RIVER	*Sq. miles*													
Above Pittsburgh	19,020	Average	3.71	3.07	3.77	3.51	3.94	4.45	4.66	3.73	3.21	2.85	2.74	3.33	42.97
		1914	3.23	3.19	3.03	5.15	3.67	3.98	2.82	4.85	1.34	2.70	1.71	4.90	40.57
		1915	4.98	3.11	1.52	1.55	4.49	3.86	5.54	4.80	2.92	3.42	2.80	4.42	43.41
Above Cincinnati (below Licking).	76,320	Average	3.51	3.08	3.90	3.49	3.86	4.40	4.47	3.57	2.92	2.62	2.70	3.14	41.66
		1914	2.80	3.44	3.00	4.23	2.66	3.05	3.21	4.98	1.53	3.27	1.60	4.72	38.49
		1915	4.38	2.60	1.72	1.61	4.30	4.14	5.60	4.73	3.82	3.00	2.94	4.50	43.34
Below Tennessee River	202,700	Average	3.75	3.53	4.59	3.92	3.89	4.26	4.40	3.67	3.06	2.62	3.04	3.65	44.38
		1914	2.51	3.51	3.38	3.97	2.26	2.77	3.41	5.26	2.19	3.71	1.70	5.26	39.93
		1915	4.60	2.59	1.99	1.37	5.44	4.27	5.43	6.00	3.91	3.00	3.96	5.61	48.17
TRIBUTARY WATERSHEDS															
Allegheny	11,677	Average	3.48	2.99	3.48	3.38	3.91	4.28	4.47	3.67	3.35	2.92	2.80	3.26	41.99
		1914	3.22	2.82	3.05	5.02	4.40	3.88	2.41	4.72	1.34	2.66	1.90	4.32	39.74
		1915	4.77	2.92	1.43	1.20	4.10	4.15	6.10	4.97	2.75	3.25	2.67	4.26	42.57
Monongahela	7,333	Average	4.08	3.20	4.23	3.71	3.99	4.71	4.97	3.82	2.98	2.75	2.64	3.45	44.53
		1914	3.25	3.78	2.99	5.36	2.50	4.14	3.47	5.07	1.33	2.77	1.41	5.82	41.89
		1915	5.32	3.41	1.66	2.12	5.12	3.41	4.64	4.53	3.19	3.70	3.00	4.65	44.75
Beaver	3,148	Average	3.14	2.83	3.42	3.08	3.40	3.90	4.19	3.21	3.24	2.57	2.48	2.85	38.31
		1914	2.72	1.97	2.47	5.26	3.93	3.50	2.06	4.72	1.28	2.96	2.02	3.80	36.69
		1915	3.37	2.51	1.25	1.22	3.37	4.59	5.10	4.61	2.70	2.02	2.23	3.60	36.57
Muskingum	7,989	Average	2.99	2.66	3.57	3.14	3.63	3.85	4.38	3.27	2.80	2.35	2.47	2.87	37.98
		1914	2.05	3.11	2.53	3.95	2.63	3.84	2.17	5.09	1.47	3.56	1.85	4.54	36.79
		1915	3.79	2.17	1.39	1.50	3.81	5.32	6.78	4.49	4.46	1.80	2.97	4.08	42.56
Little Kanawha	2,281	Average	3.95	3.24	3.84	3.76	3.85	4.62	4.65	3.48	2.96	2.77	2.80	3.32	43.24
		1914	2.88	4.11	2.51	4.08	1.75	2.49	3.46	4.79	1.06	2.98	1.13	5.33	36.57
		1915	4.22	2.52	1.42	1.60	3.49	3.70	5.72	4.91	4.55	4.14	3.35	5.11	44.73
Hocking	1,227	Average	3.31	2.76	3.65	3.21	3.73	4.33	4.46	3.34	2.45	2.47	2.36	2.72	38.79
		1914	2.21	3.59	2.34	3.65	2.39	3.49	2.36	6.74	1.32	3.98	1.47	4.59	38.13
		1915	3.99	2.18	1.54	1.36	4.75	5.70	5.02	5.67	5.07	2.20	3.56	4.61	45.65
Kanawha	12,073	Average	3.74	3.36	4.17	3.78	4.00	4.88	4.55	3.91	2.86	2.73	2.75	3.20	43.93
		1914	3.33	3.75	3.67	3.90	1.67	1.78	4.58	4.62	1.91	3.36	1.63	5.28	39.48
		1915	4.72	3.10	1.71	2.02	3.99	3.24	4.39	4.24	4.66	3.49	2.92	4.17	42.65
Guyandotte	1,659	Average	3.68	3.45	4.38	4.08	3.90	4.84	4.97	3.42	2.61	2.39	2.69	3.46	43.87
		1914	3.18	3.68	3.42	4.19	1.65	2.49	4.44	4.65	2.18	3.03	1.12	5.54	39.57
		1915	5.21	2.75	4.79	3.45	5.11	4.39	5.80	3.63	3.83	2.68	3.32	4.86	49.82

TABLE No. 25.—*Monthly and annual rainfall on Ohio watershed and on various tributaries thereof: Average for period of record to 1913, and actual for years 1914 and 1915*—Continued

Drainage area	Area		Rainfall, inches depth												
			Monthly												Total yearly
			January	February	March	April	May	June	July	August	September	October	November	December	
TRIBUTARY WATERSHEDS—continued	*Sq. miles*														
Big Sandy	4,219	Average	3.54	3.29	4.54	3.93	4.20	5.09	4.85	3.58	2.62	2.41	2.69	2.97	43.71
		1914	2.47	3.52	3.98	3.95	2.07	2.38	4.72	5.04	2.18	2.98	1.34	5.38	40.01
		1915	4.53	2.60	2.60	1.53	4.78	4.04	5.80	4.52	2.60	3.46	3.63	5.59	45.68
Scioto	6,529	Average	3.00	2.85	3.63	3.18	3.72	3.92	3.95	3.14	2.76	2.40	2.71	2.84	38.10
		1914	2.10	3.77	2.38	3.45	2.42	2.72	2.61	5.25	1.27	4.12	1.35	3.59	35.03
		1915	3.48	1.74	1.54	1.33	4.30	4.59	6.81	5.09	4.77	2.47	2.78	4.40	43.30
Little Miami	1,762	Average	3.18	2.92	3.64	3.01	3.78	3.93	3.65	3.46	2.53	2.37	3.15	2.62	38.24
		1914	2.38	3.78	2.32	3.09	1.63	2.23	2.87	5.68	0.97	3.70	1.35	3.18	33.18
		1915	3.58	1.44	1.50	1.37	5.33	4.06	4.90	5.89	5.27	2.70	2.63	4.25	42.92
Licking	3,651	Average	3.82	3.45	4.65	3.53	3.82	4.17	4.11	3.59	2.62	2.44	3.02	3.46	42.68
		1914	2.33	4.34	2.66	2.81	2.34	2.47	3.11	6.18	1.60	4.21	1.35	4.21	37.61
		1915	3.84	1.51	2.11	1.11	6.23	4.66	5.79	5.68	3.43	2.76	3.30	6.10	46.52
Miami	5,396	Average	3.05	2.97	3.78	3.17	3.89	3.93	3.48	3.10	2.83	2.48	2.96	2.80	38.44
		1914	2.36	2.91	2.30	3.56	2.05	2.88	2.66	4.98	1.33	3.17	1.32	3.20	32.72
		1915	3.25	1.44	1.44	1.81	4.65	3.95	6.46	5.77	4.54	2.29	2.39	4.05	42.04
Kentucky	7,058	Average	4.19	3.77	5.01	3.91	3.75	4.24	4.31	3.73	2.91	2.34	3.00	3.97	45.13
		1914	2.69	3.66	3.61	3.44	2.15	3.24	4.11	5.83	2.77	5.44	1.29	5.18	43.41
		1915	4.83	1.68	2.43	0.89	6.09	4.45	6.65	6.62	3.09	3.96	4.15	7.43	52.27
Salt	2,851	Average	4.11	3.72	4.68	4.15	3.51	4.14	4.13	3.39	2.79	2.31	3.25	3.80	43.92
		1914	2.22	5.03	2.76	3.05	1.49	2.18	2.51	5.87	2.65	5.08	1.06	4.62	38.51
		1915	4.79	1.66	1.89	0.90	6.86	4.56	6.08	5.19	3.74	3.20	4.45	8.09	51.48
Green	9,154	Average	4.52	3.94	5.01	4.43	3.81	3.75	4.27	3.38	3.15	2.49	3.43	4.12	46.30
		1914	1.98	4.05	3.61	3.76	2.37	1.49	2.19	4.95	3.28	5.75	1.32	5.39	40.14
		1915	5.38	1.78	1.53	0.89	8.13	4.91	4.19	6.78	3.34	3.45	5.34	8.25	53.97
Wabash	32,476	Average	2.99	2.83	3.92	3.44	3.90	3.84	3.67	3.25	3.12	2.62	3.13	2.75	39.46
		1914	2.26	3.09	2.37	3.13	2.11	2.16	1.75	4.67	2.70	2.61	1.07	2.94	30.[illegible]6
		1915	3.37	1.77	1.17	1.49	6.45	3.85	6.31	6.86	3.35	1.33	2.82	4.39	43.16
Cumberland	17,936	Average	4.57	4.10	5.43	4.78	3.96	4.34	4.74	3.70	3.16	2.62	3.67	4.39	49.46
		1914	2.52	3.50	4.87	4.11	2.64	3.10	4.74	6.71	2.81	4.92	1.58	6.60	48.10
		1915	5.75	2.58	2.75	0.82	6.34	4.98	4.47	7.03	4.55	3.70	6.77	6.94	56.68
Tennessee	40,608	Average	4.21	4.46	5.77	4.59	3.96	4.51	4.91	4.28	3.26	2.72	3.12	4.80	50.59
		1914	2.36	3.81	4.22	4.43	1.69	2.80	4.80	5.51	2.31	4.01	2.68	7.67	46.29
		1915	5.40	3.78	2.85	1.31	5.34	4.41	4.74	6.68	4.39	3.87	5.05	6.95	54.77

Run-off, 1914 and 1915.—Within the nine and one-half months, from January 1 to October 15, 1914, when laboratory examinations were being made at numerous sampling stations, distributed more or less throughout the length of the river, the run-off varied widely, as shown in detail in Table No. 16. For the watershed as a whole the run-off during the first three months averaged 1.3 inches, ranging from 0.92 inch in January to 1.98 inches in March. The maximum run-off, 3.35 inches, occurred in April. During the next month, May, the run-off dropped to 1.6 inches, so that stream-flow conditions in this month were similar to those in January, February, and March. From June to October, inclusive, the run-off was consistently and

unusually low, ranging from 0.38 inch in June to 0.11 inch during the first half of October. A more detailed study of the data presented in Table No. 16 shows that the variations from month to month in all the major subdivisions of the watershed were substantially similar, but that the range of differences between high and low discharges was greater in the upper than in the lower portion of the watershed. Thus, from January to June the run-off from the upper portions of the drainage area generally exceeded that from the lower portions; but during the low-water periods, from July to October, this relation was reversed.

The two years 1914 and 1915 may be compared satisfactorily only upon the basis of run-off at Cincinnati and Louisville, since discharge estimates as well as laboratory studies were limited to the river stretch from Cincinnati to Louisville after October 15, 1914. For the area above Cincinnati records are also available for previous years, so that the run-off from this area in 1914 and 1915 may be compared with the average for a series of years in the past. A general comparison of these two years with each other and with previous years is presented in the following summary:

Ohio watershed above Cincinnati

	Rainfall	Run-off	
	Inches	*Inches*	*Per cent of rainfall*
1914 (year)	38.5	15.1	39.2
1915 (year)	43.3	16.6	38.3
Previous years, average	[1] 41.	[2] 16.	40.0

[1] Average for years of record, varying at different observation stations.
[2] Average for years 1899–1910, from unpublished data of U. S. Geological Survey.

As shown by this comparison, the year 1914 was deficient both in rainfall and in run-off. In 1915 the run-off corresponded almost exactly to the average, notwithstanding that the rainfall was distinctly in excess of the average. This apparent inconsistency is due to the fact that an unusually large proportion of the rainfall in 1915 occurred during the summer months when the ratio of run-off to rainfall is normally low. Upon the basis of annual totals the two years do not appear very different; but when compared in more detail, month by month, they are found to differ widely, due to radically different seasonal distribution of rainfall. These differences are shown in summary in Table No. 26 following, and in figures 4 and 5, Section I.

Table No. 26.—*Rainfall and run-off on Ohio River watershed above Miami River (at Cincinnati), by months, 1914, 1915, and previous years*

Months	Rainfall, inches			Run-off, inches		
	1914	1915	Average previous years	1914	1915	Average 1896–1913
January	2.80	4.38	3.51	1.56	2.64	2.19
February	3.44	2.60	3.08	2.47	3.34	1.94
March	3.00	1.72	3.90	2.63	1.22	3.26
April	4.23	1.61	3.49	3.81	.59	2.46
May	2.66	4.30	3.86	1.96	.83	1.53
June	3.05	4.14	4.40	.32	1.07	.99
July	3.21	5.60	4.47	.30	1.22	.83
August	4.98	4.73	3.57	.25	.84	.63
September	1.53	3.82	2.92	.27	.79	.43
October	3.27	3.00	2.62	.25	1.06	.46
November	1.60	2.94	2.70	.17	.85	.61
December	4.72	4.50	3.14	1.15	2.19	1.19
Total	38.49	43.34	41.66	15.14	16.64	16.52
March–May	9.89	7.63	11.25	8.40	2.64	7.25
June–November	17.64	24.23	20.68	1.56	5.83	3.95

As compared with previous years the high discharges in December, January, and February, 1914 and 1915, and in March and April, 1914, are quite usual, but in each year distinctly unusual conditions occurred, namely:

(1) The extremely and consistently low run-off during the six months June to November, 1914. Low water is expected during these months, but such low stages as were observed in 1914 are exceptional and are rarely maintained for such a long period.

(2) The low discharges during March and April. 1915, occurring at a season when freshets are much more usual.

(3) The fairly high discharges observed from June to November, 1915.

It may be said, on the whole, that during December, January, and February the run-off in the two years was similar and more or less normal; but during the remainder of the seasonal cycle the two years are in marked contrast.

The differences between the two years, and their divergences from the "normal," are further illustrated by the data of Table No. 27, showing the frequency distributions of daily discharges. Upon this basis of comparison the 1915 frequencies are very close to the average for the period taken as the basis of comparison; whereas 1914 differs markedly from this distribution, in a much higher frequency of discharges in the lowest range, and a lower frequency of moderately low discharges (0.5 to 1.5 second-feet per square mile).

The contrast between conditions in the summer of 1914 and those in the corresponding period of 1915 is again shown by the fact that the wickets of Dam No. 37 were kept raised only 23 days from June 1 to September 30, 1915, whereas during this period of 1914 the wickets were kept raised continuously.

TABLE No. 27.—*Number of days in which discharge of Ohio River at Cincinnati was within designated ranges, 1914, 1915, and average for years 1858–1912*

Discharges: Second-feet per square mile	Frequency, days		
	1914	1915	Average 1858–1912[1]
Under 0.5 foot	186	118	128
0.5 to 1 foot	23	92	82
1 to 1.5 feet	40	61	53
1.5 to 2 feet	38	39	30
2 to 2.5 feet	33	13	21
2.5 to 3 feet	20	12	15
3 to 4 feet	21	16	20
4 to 5 feet	4	8	10
5 to 6 feet	0	4	4
Over 6 feet	0	2	2
	365	365	365

[1] Figures for period 1858–1912 derived from Report of Plan of Sewerage, City of Cincinnati, Table 11, p. 331.

GENERAL NOTE.—The figures in above table are derived from gage height readings at Cincinnati, employing a rating table for discharge of the Ohio at Cincinnati loaned by the United States Geological Survey, and taking drainage area above Cincinnati as 76,320 square miles (including Licking Basin).

Ratio of run-off to rainfall.—The ratio of run-off to rainfall, by months, during 1914 and 1915, on the areas for which the required data are available, is shown in Table No. 28.

TABLE No. 28.—*Percentage which run-off is of rainfall on Ohio watershed above certain points and on tributary watersheds, by months, 1914 and 1915*

1914

	Drainage area	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Ohio watershed:	*Sq. miles*													
Above Pittsburgh	19,020	73	73	115	90	70	14	12	5	15	----	----	----	----
Above Wheeling	24,980	69	78	112	94	70	12	11	4	15	----	----	----	----
Above Parkersburg	37,950	63	67	95	93	61	10	11	4	16	----	----	----	----
Above Hocking[1]	40,490	63	67	96	93	62	10	11	4	16	----	----	----	----
Above Point Pleasant	52,690	63	70	84	87	66	10	11	4	16	----	----	----	----
Above Big Sandy[1]	60,570	58	70	80	86	69	10	9	5	16	----	----	----	----
Above Little Miami[2]	70,950	54	68	79	86	72	10	9	5	18	7	11	27	38.1
Above Cincinnati[3]	76,320	54	69	81	86	72	10	9	5	17	8	11	25	37.8
Above Kentucky[2]	83,130	52	68	83	85	70	10	9	5	17	9	10	27	37.8
Above Louisville	91,190	50	74	81	89	72	11	9	7	16	8	10	29	38.2
Above Evansville	107,100	49	72	77	88	80	13	9	5	19	----	----	----	----
Above Cumberland[2]	144,000	42	61	75	81	70	13	9	5	14	----	----	----	----
Above Tennessee[2]	161,960	41	64	71	92	74	14	10	5	15	----	----	----	----
Above Tennessee[1]	202,700	37	56	59	85	70	14	10	6	15	----	----	----	----
Tributary watersheds:														
Allegheny	11,680	69	83	123	94	76	17	15	4	16	----	----	----	----
Monongahela	7,339	98	69	122	93	56	10	17	6	11	----	----	----	----
Beaver	3,140	110	67	120	80	70	9	8	3	11	----	----	----	----
Scioto	6,410	46	61	144	89	53	6	5	3	11	----	----	----	----
Little Miami	1,714	42	60	162	111	77	5	5	7	10	12	8	20	41.2
Licking	3,636	46	87	82	62	54	13	1	4	4	27	5	46	36.8
Miami	5,410	33	58	135	83	46	9	8	5	13	8	12	14	34.4
Kentucky	6,912	22	48	38	58	40	7	3	3	9	12	5	24	21.5
Wabash	32,890	19	31	78	74	42	14	9	3	6	----	----	----	----
Cumberland	17,860	14	50	32	135	62	9	11	7	15	----	----	----	----
Tennessee	40,740	28	42	36	78	73	17	11	9	19	----	----	----	----

1915

	Drainage area	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Ohio watershed:														
Above Little Miami[2]	----------	63	121	77	38	20	27	19	18	20	35	29	46	38.2
Above Cincinnati[3]	----------	63	130	74	38	20	26	20	18	20	35	30	47	39.0
Above Kentucky River[2]	----------	60	127	72	35	19	25	22	17	19	36	31	54	38.6
Above Louisville	----------	65	144	72	38	18	28	22	17	20	35	30	54	39.7
Tributary watersheds:														
Little Miami	----------	50	514	29	14	8	21	22	24	33	34	23	116	50.6
Licking	----------	77	208	64	38	23	26	40	14	11	33	41	88	46.5
Miami	----------	26	247	45	22	13	22	38	20	29	43	29	35	35.4
Kentucky	----------	45	114	48	49	10	20	24	11	12	22	27	76	33.5

[1] Including designated tributary. [2] Excluding designated tributary. [3] Including Licking watershed.

The seasonal variation indicated in 1914, namely, a high ratio of run-off to rainfall during the winter and spring, with a much lower ratio during summer and autumn, is characteristic, except that the run-off does not ordinarily fall to such a low ratio as observed in the summer and autumn of 1914. It may be noted, in this connection, that in the summer and autumn of 1915, the ratio of run-off to rainfall was quite constantly and greatly in excess of that in corresponding months of 1914. Thus, the difference in summer rainfall in the two years was associated with a proportionately much greater difference in run-off. The low ratio of run-off during the spring of 1915, especially in April and May, is quite unusual.

Velocities of flow.—The characteristics of the channel of the Ohio River are such that the velocities in successive prisms are much more nearly uniform at high than at low river stages, as may be seen by reference to Table 20. Thus, during the five months, January to May, 1914, with mean monthly discharges at Cincinnati varying from 100,000 to 248,000 second-feet, the extreme range of velocities in the 26 stretches included in Table No. 20 is from 1.47 to 3.53 miles per hour, and the great majority of observations fall within the range from 2 to 3 miles per hour. Considering only longer stretches, the variation at high stages is still narrower. For example, in the month of highest discharge, April, 1914, the velocity in any stretch of 100 miles or more will be found to vary but little from the mean rate of 3 miles per hour.

At low stages the velocities in different stretches vary more widely, due in part to the effect of the dams which are raised at such times, in part to differences in the shape of the low-water channel in different prisms. During the four and one-half months, June 1 to October 15, 1914, with discharges at Cincinnati ranging from 9,000 to 22,200 second-feet, the mean velocities shown in Table No. 20 vary from 0.06 to 1.63 miles per hour, a more than twenty-fold difference. The lowest velocities during this period are in the upper portion of the river, from Pittsburgh to Wheeling, where the low-water flow is greatly retarded by the dams constructed for improvement of navigation. The highest low-water velocities are observed in the stretch from the Scioto River (mile 358) to Cincinnati (mile 461). Of the open-channel stretches not influenced by dams, the stretch between the Miami River (mile 492) and Louisville (mile 598), and especially the lower half of this stretch (miles 543–598) is remarkable for the very low velocities reached at low river stages and for the wide range of variation between high and low stages, due to the broad and relatively flat contour of the low-water channel. The range

between high-water and low-water velocities in these three stretches is shown in the following summary:

Stretch	Monthly mean velocities				
	Miles per hour		Ratio		
	Maximum [1]	Minimum [2]	Minimum	:	Maximum
Pittsburgh to Wheeling (0–77 miles)	3.05	0.10	1	:	30
Scioto River to Cincinnati (358–461 miles)	3.01	1.00	1	:	3
Miami River to Louisville (492–598 miles)	3.11	0.25	1	:	12.5

[1] Mean for April, 1914. [2] Mean for Oct. 1–15, 1914.

From the standpoint of this study, which is concerned particularly with the phenomena of natural purification in the river, velocities are of significance chiefly (though not solely) as permitting the calculation of times of flow between given points, especially between the large cities, Pittsburgh, Wheeling, Cincinnati, and Louisville. The maximum and minimum times of flow during 1914 from each of these cities to each other city situated downstream, and to Paducah, which is near the mouth of the river, are summarized in Table No. 29.

TABLE No. 29.—*Estimated times of flow between important points on the Ohio River, corresponding to maximum (April, 1914) and minimum (October 1–15) mean discharge observed during 1914*

Origin	Mean time of flow in days, from designated point to—							
	Wheeling (station 88)		Cincinnati (station 461)		Louisville (station 598)		Paducah (station 926)	
	Oct. 1–15, 1914 [1]	April, 1914	Oct. 1–15, 1914 [1]	April, 1914	Oct. 1–15, 1914 [1]	April, 1914	Oct. 1–15, 1914 [1]	April, 1914
From Pittsburgh (station 0)	34	1.2	73	6.2	95	8.1	129	12.8
From Wheeling (station 97)			37	4.9	58	6.7	93	11.5
From Cincinnati (station 475)					20	1.6	54	6.4
From Louisville (station 611)							31	4.6

[1] The times of flow estimated for the period Oct. 1–15 are the times that would have been required had the stream-flow conditions obtaining in that period remained constant. As this was not actually the case the intervals given are hypothetical, but probably represent about the maximum intervals to be expected in long-continued stages of extreme low water.

Although these maxima and minima are based on only 10 months' observations, they probably represent very nearly the extremes of variation which would be observed in a long series of years, for higher river stages than occurred in 1914 would not greatly increase velocities, and stages as low as observed in the first half of October, 1914, are seldom if ever maintained long enough for the corresponding time of flow from Pittsburgh to Paducah to be actually realized. (See footnote to Table No. 29.) With the construction of the additional dams which are projected for improvement of navigation the time of flow through the river at low stages will be materially increased.

SECTION III

SOURCES OF POLLUTION

By R. E. TARBETT, W. H. FROST, and J. K. HOSKINS

The pollution of a river system at any given point in its course depends upon:

(1) The amount and composition of all the wastes discharged into the waterway above this point;

(2) The volume of water in which they are diffused; and

(3) The direction and extent of the changes which the wastes have undergone between their original sources and the point of observation.

An ideal analysis would, therefore, include as one of its requisites, measurements of the volume or discharge at the observation point. This is the simplest of the requirements and can ordinarily be fulfilled without excessive difficulty.

The next requirement is some measure of the pollution at the observation point in terms of the weights of various chemical compounds or elements and the number and kinds of organisms per unit of volume. This is fulfilled to some extent by the physical, chemical, and biological examination of water by conventional methods. The results have the virtue that they are expressed in definite, quantitative terms, although it is well understood that they are incomplete and, in many instances, indirect measures of the kind of pollution which is of greatest sanitary and economic importance.

The next requirement would be an evaluation and summation of all the sources which contribute to each constituent which is differentiated in the analysis of the water, the sources being evaluated in the same terms as the analysis, that is, in weights of each chemical constituent, and in the numbers of each class of organisms. Then, by summation of the amounts of each constituent accounted for at all sources and comparison of this total with the amount found in the stream by direct analysis, it would be possible to determine the aggregate of changes which had taken place between original sources and observation point.

But even this would not at all accurately evaluate individual sources with respect to their share in any given item of pollution at the observation point, for the wastes from different sources would presumably have been subject to changes in different degree, pro-

portionate, perhaps, to their respective distances from the observation point. To account for this it would be necessary to know the rates at which the indicated changes were taking place in relation to determinable conditions, such as distance, time, temperature, etc., and to apply these rates to the various sources, classified according to these conditions. Even then it could not be assumed that the quantitative relations existing between these sources and the observed pollution were constant, since all the governing conditions might be subject to variation from day to day, and it would be necessary to ascertain the laws governing these variations. Obviously, all these requirements can not be fulfilled as yet, and it is therefore beyond all present reckoning to establish such general and fundamental quantitative relations as will serve to allocate all the waste constituents present in a watercourse to their respective sources in any exact proportion and under all conditions.

Aside from the fact that the laws governing the chemical and biological changes which take place in watercourses are still unknown, certain of the important sources of pollution can not as yet be evaluated in the terms used in chemical and biological analysis. For example, a rural watershed may be described in terms of its area, its general topography and geology, its state of forestation or cultivation, its population, etc. But such data, even in great detail, do not permit any definite quantitative estimate to be made of the amount of nitrogen, for example, or the weight of suspended matter which is contained in its run-off; for while these amounts may be influenced by each of the above-mentioned variables they are not related to any of them in a well-defined and simple manner. Moreover, the run-off from such an area is not constant, but varies from day to day both in amount and in character. It is, therefore, practically impossible, in a survey of rural drainage areas, to collect data which will lead to anything but a very rough estimate of the character and amount of wastes which any such area will contribute to a watercourse which receives its drainage.

With respect to urban areas which are provided with sewerage systems the case is different, for here the wastes bear a fairly definite and constant ratio to the numbers of inhabitants served by the sewers, which is readily determinable. They also bear a less constant but not altogether indeterminate ratio to data which can be collected concerning the industries contributing industrial sewage. A statement of the sewered population and a summary of salient facts regarding the industries discharging trades wastes into the sewers of a community may, therefore, be translated at least roughly into the same terms which are used to express the results of direct chemical and biological examinations of water, that is, weights of certain chemical constituents or indices, and numbers of certain

classes of bacteria. The conversion is certainly not very precise as applied to individual communities and industries; but, as applied with due care to large aggregates of population and industries, it may be expected to be reasonably accurate.

It will be convenient, therefore, to separate the sources of pollution into two broad classes, namely:

(1) Sources contributing to pollution by the discharge of domestic or industrial sewage directly into the river system, and

(2) Sources contributing to the pollution only by natural drainage.

Chief importance is attached, in this study, to the sources of the first class, contributing direct sewage pollution, primarily because they are the only sources of which quantitative estimates can be made in terms similar to those employed in direct analysis. They are, however, of major importance for several other reasons, namely: The wastes from these sources contain the most offensive and dangerous kinds of organic refuse, discharged into the river system in high concentration and not reduced in offensiveness by processes of natural purification prior to their entry into the watercourse. In the aggregate, they contribute a very considerable proportion of the total organic pollution, especially the bacterial pollution observed at some points on the river; and finally, they are the only sources which are controllable. Such a survey of sources of pollution as is here attempted is, therefore, for the most part, a summary of urban population, more especially of the population tributary to sewerage systems, with additional summaries of organic industrial wastes, reduced, so far as available data permit, to the same terms that are used in the summation of sewered population.

As to unsewered areas, no attempt is made to arrive at any direct estimate of the pollution which they contribute, for while it may be shown that they must necessarily contribute a large proportion of certain classes of waste constituents found in the river, there are no terms in which the different areas may be compared or summarized. Subdivisions of the drainage basin have already been described in terms of area; and in the summaries which follow, statistics of their population are given; but it is obvious that these data furnish little information as to the pollution which the rural areas contribute, since this is not directly related either to size or to population.

POPULATION

The statistics of population used in this study are derived originally from the Federal Census enumerations of 1890, 1900, and 1910, as published in the reports of the census of 1910,[1] redistributed according to drainage areas, and extended to the year 1915 by assuming an arithmetical rate of increase since 1910.

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[1] Thirteenth Census of the United States, 1910, Vols. II and III, Population, Washington, 1913.

As published in the census reports, the population of each State is distributed primarily by counties; and the population of each county is further distributed according to the civil subdivisions which make up the county area. The organization of the county varies in different States; but in all the States which have territory in the Ohio Basin the county is subdivided into several districts, which are variously designated as "districts," "townships," or "towns." Within these areas are more or less independent "incorporated communities," which may be called cities, villages, or boroughs, which are enumerated in the census reports as separate units. The "townships" or "districts" are rural areas, usually comprising some 25 to 50 square miles each, while the incorporated places are small areas of compact population.

In the classification of the Census Bureau the population resident in incorporated places having 2,500 or more inhabitants is classed as "urban," [2] and the remainder of the population, residing in the country and in incorporated places of less than 2,500 inhabitants is classed as rural. This classification is, therefore, followed in this report.

Methods of compilation.—In order to regroup the population of civil divisions according to drainage areas, each watershed was first carefully outlined on a United States post-route map,[3] the boundaries being adjusted in accordance with topographic maps of the United States Geological Survey where these were avialable. The post-route maps used show the locations of all incorporated places, and the boundaries of counties, but do not show the boundaries of townships or corresponding subdivisions.

Counties lying wholly within a single watershed require only simple summation of their populations, classified as rural and urban, respectively. In apportioning the population of counties intersected by the watershed boundary, the proportion of the country area lying within the watershed was first determined from the map, by planimeter measurement. Then the population of all incorporated places was deducted from the total for the county, and the remainder prorated, allocating to the watershed a fraction of this population proportionate to the fraction of the county area included in the watershed, as previously shown by planimeter measurement. To this prorated population was then added the population of all incorporated places of less than 2,500 inhabitants actually lying within the watershed as shown by the base map, thus giving the total rural population. The urban population is, of course, the sum of the populations of incor-

[2] In the Mortality Statistics published by the Census Bureau, "urban" population includes only that resident in incorporated places having 10,000 or more inhabitants.

[3] The United States post-route maps used were furnished by the Post Office Department. They are published in sheets each of which shows a single State or portions of two or more adjacent States. The scale varies in the maps used from 1 inch=5 miles to 1 inch=8.45 miles.

porated places of 2,500 or more inhabitants lying in that portion of the county included in the watershed.

In thus apportioning the population of unincorporated places according to area it is necessarily assumed that this population is uniformly distributed over the county and that the total area of incorporated places is negligible. Actually the distribution is not entirely uniform, and the areas of incorporated places are not altogether negligible, so that some errors are involved, but these are presumably compensating in the summations for a large watershed.

In the densely populated districts immediately adjacent to Pittsburgh and Cincinnati, population estimates have been made with somewhat greater precision by using more detailed maps, showing the boundaries of the smaller civil divisions, such as townships and city wards, in relation to watershed boundaries which were likewise more accurately defined by topographic maps.

Summaries of population were thus prepared for each major drainage area for each of the census years 1890, 1900, and 1910, and from these data post-censal estimates of population as of July 1, 1915, have been prepared for each area, in accordance with the practice of the Census Bureau, using the arithmetical method, basing the estimated post-censal increase upon the observed rate of increase during the last intercensal period.[4] Estimates of the 1915 population of individual cities having 8,000 or more inhabitants in 1910 have been taken from the intercensal population estimates for these places as issued from year to year by the Census Bureau, taking into account any changes in area due to annexations of additional territory subsequent to the census enumeration. For incorporated communities of less than 8,000 inhabitants individual estimates of 1915 population have not been attempted, but for each watershed an estimate has been made for the aggregate of these communities. The total population of each watershed, urban and rural combined, has been estimated for 1915 from the total populations of 1900 and 1910. The rural population for 1915 has then been taken as the difference between the total population and the urban population.[5]

Population of the Ohio River Basin as a whole.—The statistics of population for the Ohio River Basin as a whole are summarized in Table No. 30, which shows the total, urban and rural populations as compiled for the census years 1890, 1900, and 1910, and as estimated for 1915; also the percentage of increase in each class of population in the decades 1890–1900 and 1900–1910. During these two decades the total population of the watershed increased by 3,445,000, or

[4] The census enumeration of 1910 is dated April 15, while the 1900 enumeration is of June 1, so that the intercensal interval is 118.5 months.

[5] In making these estimates it has been convenient to carry out the computations to the nearest whole number, in order that totals might check; hence, figures which are not presumed to be accurate beyond the third digit, are given in detail in the tabulations. In applying the figures, and generally in referring to them, round numbers are used.

approximately 31 per cent. The greater part of this increase was in the urban population, which was almost doubled from 1890 to 1910, while the rural population increased only about 11.3 per cent. Mean densities of population for periods corresponding to those of Table No. 30 are shown in Table No. 31.

TABLE No. 30.—*Summary of population of the Ohio River Basin 1890–1915*

	Population				Per cent increase	
	July, 1, 1915 (estimated)	Federal census			1900–1910	1890–1900
		Apr. 15, 1910	June 1, 1900	June 1, 1890		
Total	15, 381, 200	14, 474, 250	12, 754, 466	11, 029, 118	13. 48	15. 63
Rural	9, 686, 600	9, 375, 895	8, 993, 664	8, 305, 939	4. 25	8. 28
Urban	5, 694, 600	5, 098, 355	3, 760, 802	2, 723, 179	35. 55	38. 12

TABLE No. 31.—*Density of population of the Ohio River Basin, 1890–1915*

	Population per square mile			
	1915 (estimated)	1910	1900	1890
Total	76	71	63	54
Rural	48	46	44	41
Urban	28	25	19	13

In Table No. 32, the population of the Ohio Basin, in the year 1910, is compared with that of the continental United States and of the divisions into which the States are customarily grouped. As shown by this table, the population of the watershed at that time constituted 15.8 per cent of the total population of the United States. It is more than twice as great as the population of the New England States; somewhat less than that of the Middle Atlantic or East-North Central States; somewhat greater than that of the West-North Central or South Atlantic States; and more than twice that of the entire area west of the Dakotas, Kansas, and Texas. The percentage of rural population is less than in the United States as a whole due to the higher proportion of urban population in the eastern and westeri coastal regions; but is above the average for the area between the Appalachians and the Rocky Mountains. Notwithstanding the comparatively low percentage of urban population, the mean density of population in the watershed is greater than that of the country as a whole, and is exceeded only in the New England, Middle Atlantic, and East-North Central divisions. The rate of increase in population during the decade 1900–1910 was less than in the country as a whole, but in urban population the increase, 35.55 per cent, was still at a very rapid rate. On the whole, as regards density of population, ratio of rural to urban residents, and rate of

increase in urban population, the Ohio Basin is fairly representative of the entire United States, being intermediate between the extremes found in various other sections of the country.

TABLE No. 32.—*Population of the Ohio River Basin compared with that of the continental United States and its divisions—Urban, rural, and total populations for 1910, percentage increase 1900–1910, and density per square mile, 1910*

Areas	Population, 1910 Federal census	Classification of population		Percentage increase, 1900–1910			Density of population per square mile, 1910
		Urban	Rural	Total	Urban	Rural	
		Per cent	*Per cent*				
Ohio drainage area	14, 474, 250	35. 2	64. 8	13. 48	35. 55	4. 25	71. 4
Continental United States	91, 972, 266	46. 3	53. 7	21. 0	38. 4	9. 2	30. 9
New England States	6, 552, 681	83. 3	16. 7	17. 2	22. 0	[1] 2. 2	105. 7
Middle Atlantic States	19, 315, 892	71. 0	29. 0	25. 0	36. 2	4. 0	193. 2
East-North Central States	18, 250, 621	52. 7	47. 3	14. 2	33. 2	[1] 1. 5	74. 3
West-North Central States	11, 637, 921	33. 3	66. 7	12. 5	31. 5	4. 9	22. 8
South Atlantic States	12, 194, 895	25. 4	74. 6	16. 8	38. 5	10. 9	45. 3
East-South Central States	8, 409, 901	18. 7	81. 3	11. 4	39. 2	6. 5	46. 8
West-South Central States	8, 784, 534	22. 3	77. 7	34. 5	85. 2	24. 7	20. 4
Mountain States	2, 633, 517	36. 0	64. 0	57. 3	75. 0	48. 8	3. 1
Pacific States	4, 192, 304	56. 8	43. 2	73. 5	112. 2	39. 8	13. 2

[1] Decrease.

Distribution of population by States and by drainage areas.—Table No. 33 shows the distribution of population in the watershed by States for the census year 1910, and as estimated for the year 1915; also the percentages of increase in total population in the decades 1890–1900 and 1900–1910. Excepting the very small area of Mississippi which lies within the watershed, the greatest increase in population in these two decades has been in the eastern portion of the watershed, chiefly in Pennsylvania and West Virginia, due to the active development of mining and allied industries.

TABLE No. 33.—*Population of the Ohio River Basin by States, urban, and total population for 1910 and estimated for 1915, with percentage increase 1900–1910 and 1890–1900*

State	Area in basin	Population of portion in Ohio Basin					
		Urban		Total			
		July 1, 1915 (estimated)	1910	July 1, 1915 (estimated)	1910	Percentage increase	
						1900–1910	1890–1900
	Sq. miles						
New York	1, 942	58, 600	51, 832	140, 000	131, 757	13. 5	13. 4
Pennsylvania	15, 528	1, 557, 700	1, 381, 794	2, 981, 200	2, 648, 324	31. 3	28. 2
Maryland	430			14, 100	13, 325	13. 1	26. 7
Virginia	7, 130	26, 900	23, 627	366, 600	339, 867	17. 6	20. 8
North Carolina	6, 226	23, 800	21, 580	240, 700	230, 791	8. 9	21. 7
Ohio	29, 499	1, 742, 200	1, 549, 291	3, 219, 400	3, 048, 211	11. 9	8. 0
West Virginia	20, 394	250, 000	208, 562	1, 259, 700	1, 124, 352	29. 5	27. 1
Kentucky	39, 144	584, 400	544, 215	2, 305, 800	2, 226, 046	7. 3	15. 4
Tennessee	33, 447	307, 600	276, 305	1, 666, 900	1, 606, 138	7. 7	13. 1
Georgia	1, 470			46, 400	45, 964	1. 7	13. 1
Alabama	6, 763	35, 500	32, 835	293, 400	275, 954	13. 6	10. 1
Mississippi	379			12, 300	10, 977	29. 2	11. 9
Indiana	28, 962	936, 900	860, 091	2, 218, 600	2, 171, 282	4. 3	13. 5
Illinois	11, 377	171, 000	148, 223	616, 100	601, 262	4. 9	12. 3
Total	202, 691	5, 694, 600	5, 098, 355	15, 381, 200	14, 474, 250	13. 48	15. 63

NOTES.—Population for 1910, 1900, 1890, from United States census; population for 1915 estimated according to the United States Census Bureau method.

The total and urban populations upon the various drainage areas tributary to the Ohio are shown in Table No. 34.[6] Corresponding densities of population are shown in Table No. 35, and are indicated graphically in Figures 10, 11, and 12, which give a better view of the differences between different sections of the watershed. Rates of increase in total, urban, and rural population on each drainage area are shown in Table No. 36; and Tables Nos. 37 and 38 show, respectively, the populations and densities on the entire watershed above certain points on the main stream.

TABLE NO. 34.—*Population of the principal tributary basins of the Ohio River—Total and urban population for 1890, 1900, 1910, and estimated 1915*

Basin	Population							
	Total				Urban			
	July 1, 1915 (estimated)	1910	1900	1890	July 1, 1915 (estimated)	1910	1900	1890
Allegheny	1, 175, 100	1, 071, 682	875, 641	740, 862	416, 600	364, 737	236, 547	147, 149
Monongahela	1, 075, 000	925, 120	640, 867	451, 191	429, 800	352, 665	174, 501	77, 969
Beaver	496, 900	438, 431	327, 657	280, 576	302, 600	251, 086	149, 255	101, 324
Muskingum	649, 500	616, 816	554, 812	519, 344	267, 700	234, 777	165, 121	123, 253
Little Kanawha	91, 200	91, 185	91, 221	77, 333	None.	None.	None.	None.
Hocking	117, 900	110, 333	95, 962	90, 488	39, 700	34, 574	23, 924	23, 900
Kanawha	594, 900	536, 609	426, 011	340, 849	66, 800	55, 991	31, 455	14, 835
Guyandotte	71, 800	63, 765	48, 611	41, 541	None.	None.	None.	None.
Big Sandy	234, 800	201, 612	138, 752	96, 070	3, 600	3, 561	None	None.
Scioto	580, 300	553, 115	501, 571	451, 287	308, 500	272, 845	204, 959	154, 233
Little Miami	111, 400	113, 158	116, 457	117, 567	16, 300	15, 895	15, 176	13, 430
Licking	180, 800	186, 048	196, 047	176, 913	22, 200	20, 550	17, 385	15, 382
Miami	611, 800	577, 798	513, 420	489, 174	321, 500	295, 910	230, 176	180, 927
Kentucky	367, 300	357, 448	338, 736	297, 607	70, 500	63, 792	48, 617	38, 298
Salt	131, 900	129, 604	125, 287	120, 725	10, 000	9, 636	8, 935	8, 725
Green	424, 600	416, 284	400, 521	367, 556	25, 500	22, 858	14, 445	7, 803
Wabash	2, 304, 500	2, 244, 792	2, 131, 609	1, 844, 060	907, 800	821, 252	623, 203	395, 138
Saline	66, 000	62, 880	56, 922	53, 248	11, 300	8, 675	None.	None.
Cumberland	908, 000	865, 748	785, 714	681, 105	168, 500	156, 993	111, 677	99, 560
Tennessee	1, 878, 600	1, 787, 215	1, 613, 917	1, 410, 146	242, 800	212, 110	144, 864	106, 277
Minor basins and Ohio River direct	3, 308, 900	3, 124, 607	2, 774, 731	2, 381, 456	2, 062, 900	1, 900, 448	1, 560, 562	1, 214, 976
Total basin	15, 381, 200	14, 474, 250	12, 754, 466	11, 029, 118	5, 694, 600	5, 098, 355	3, 760, 802	2, 723, 179

NOTE.—Cities at the mouths of tributaries included in Ohio River direct. 1890–1900–1910 population from United States census.

[6] In compiling these tables, cities situated at the mouths of tributaries and the entire population on the drainage areas of small streams emptying directly into the Ohio, have been considered as located directly upon the main stream.

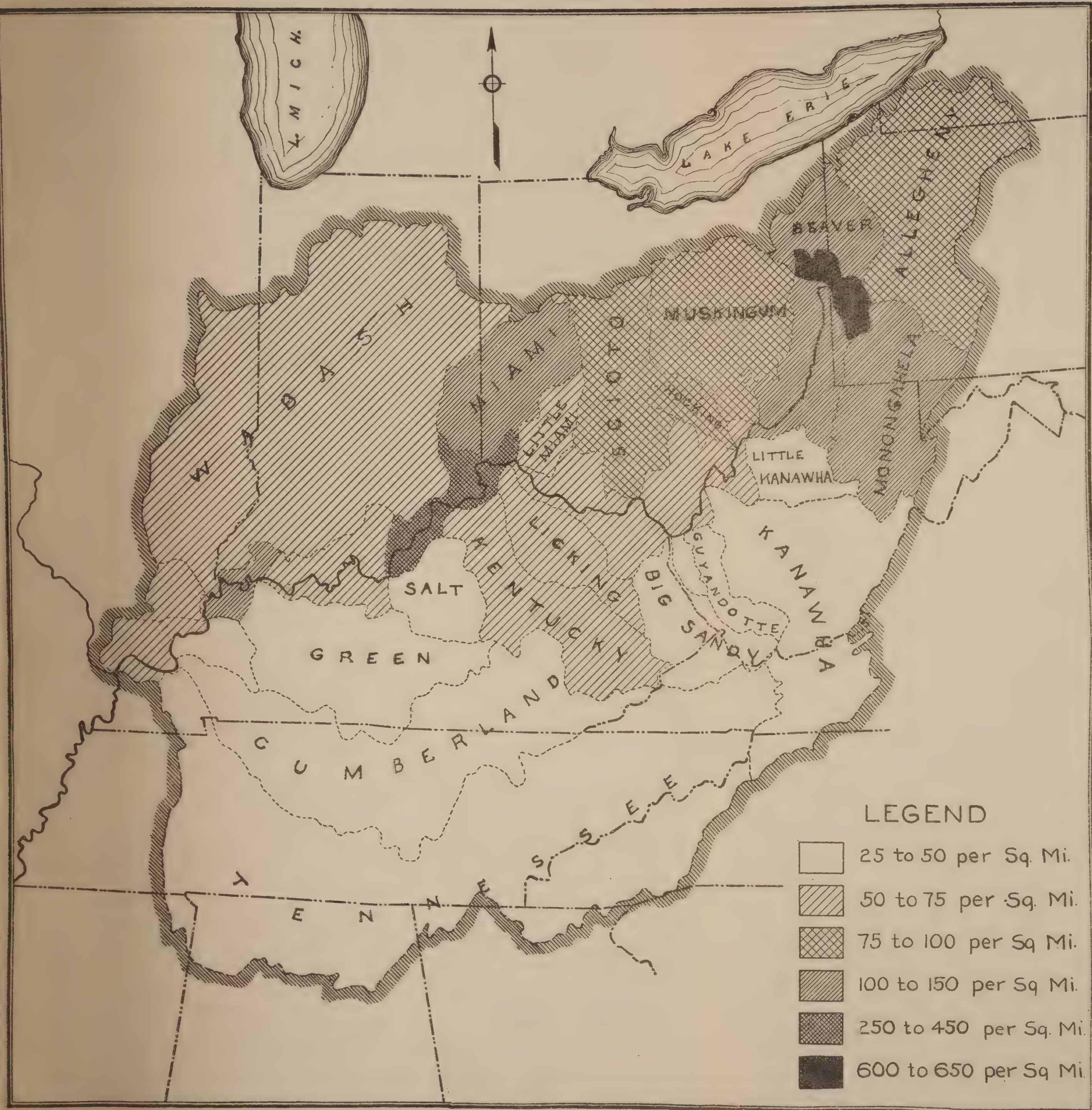

FIG. 10.—Density of population (total) on the Ohio River watershed by tributary drainage areas, 1910

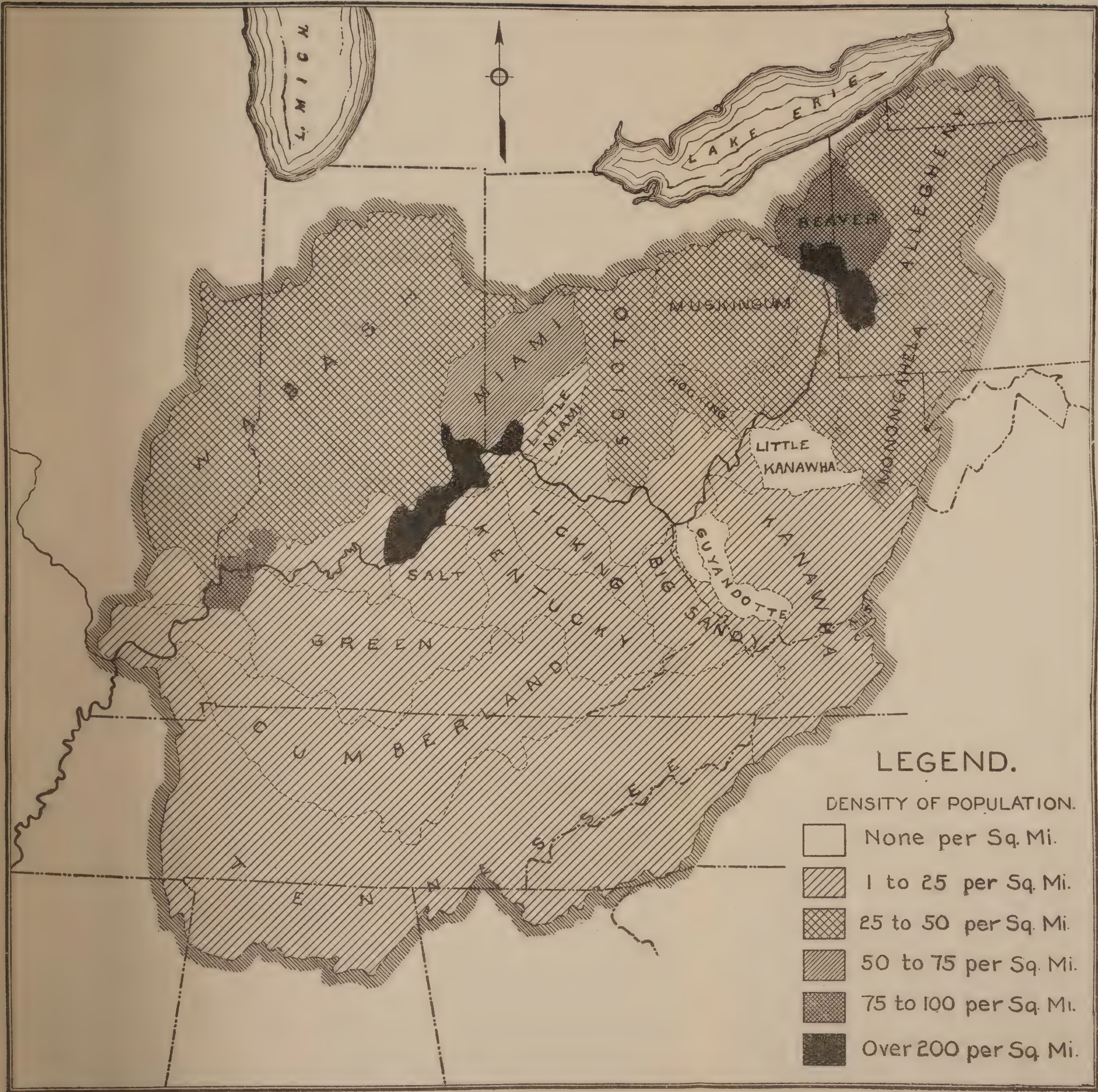

FIG. 11.—Density of urban population on the Ohio River watershed by tributary drainage areas, 1910

95404°—24. (Face p. 62.) No. 2

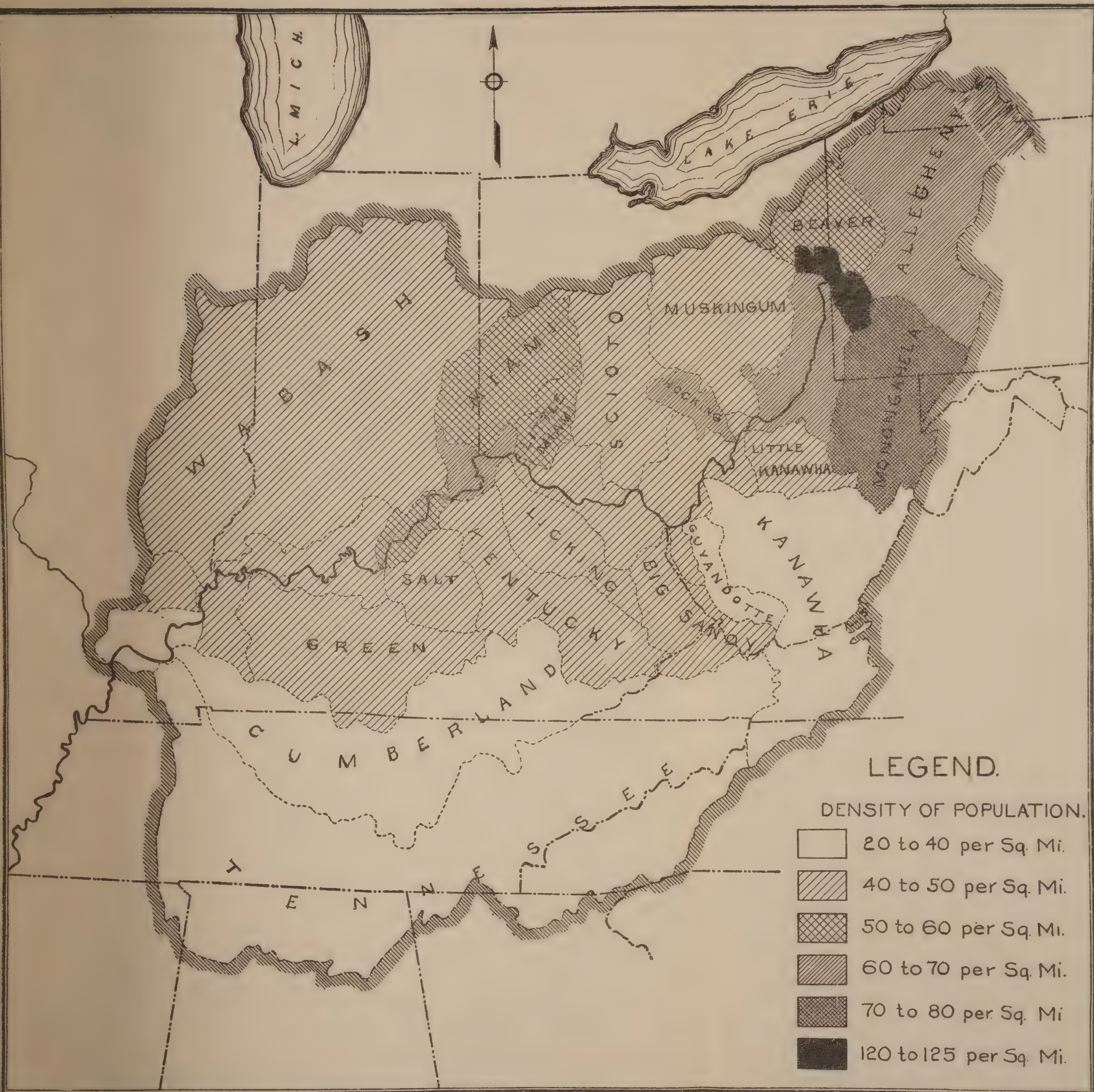

FIG. 12.—Density of rural population on the Ohio River watershed by tributary drainage areas, 1910

95404°—24. (Face p. 62.) No. 3

TABLE No. 35.—*Density of population of the principal tributary basins of the Ohio River—Total and urban population per square mile for 1890, 1900, 1910, and estimated 1915*

Basin	Area	Population per square mile							
		Total				Urban			
		1915	1910	1900	1890	1915	1910	1900	1890
	Sq. miles								
Allegheny	11, 677	100. 6	91. 8	75. 0	63. 4	35. 7	31. 3	20. 3	12. 6
Monongahela	7, 333	146. 7	126. 2	87. 4	61. 5	58. 7	48. 1	23. 8	10. 6
Beaver	3, 148	157. 8	139. 2	104. 1	89. 1	96. 1	79. 7	47. 4	32. 2
Muskingum	7, 989	81. 4	77. 2	69. 4	65. 0	33. 5	29. 4	20. 6	15. 4
Little Kanawha	2, 281	40. 0	40. 0	40. 0	33. 9	0. 0	--------	--------	--------
Hocking	1, 227	96. 1	89. 9	78. 2	73. 7	32. 3	28. 2	19. 5	19. 5
Kanawha	12, 073	49. 2	44. 4	35. 3	28. 3	5. 5	4. 6	2. 6	1. 3
Guyandotte	1, 659	43. 3	38. 2	29. 3	25. 0	0. 0	--------	--------	--------
Big Sandy	4, 219	55. 6	47. 8	32. 9	22. 8	0. 8	0. 8	--------	--------
Scioto	6, 529	88. 8	84. 7	76. 8	69. 1	47. 2	41. 8	31. 4	23. 6
Little Miami	1, 782	62. 5	63. 5	65. 4	66. 0	9. 1	8. 9	8. 5	7. 6
Licking	3, 651	49. 5	50. 9	53. 7	48. 5	6. 1	5. 6	4. 8	4. 3
Miami	5, 396	113. 4	107. 0	95. 1	90. 6	59. 6	54. 8	42. 6	33. 5
Kentucky	7, 059	52. 0	50. 6	48. 0	42. 2	10. 0	9. 0	6. 9	5. 5
Salt	2, 851	46. 3	45. 5	43. 9	42. 3	3. 5	3. 4	3. 1	3. 0
Green	9, 154	46. 4	45. 4	43. 8	40. 1	2. 8	2. 4	1. 6	0. 8
Wabash	32, 476	71. 0	69. 1	65. 6	56. 7	28. 0	25. 3	19. 2	12. 1
Saline	1, 164	56. 7	54. 1	48. 9	45. 7	9. 7	7. 5	--------	--------
Cumberland	17, 936.	50. 6	48. 2	43. 8	38. 0	9. 4	8. 7	6. 2	5. 6
Tennessee	40, 608	46. 3	44. 0	39. 8	34. 7	6. 0	5. 2	3. 6	2. 6
Minor basins and Ohio River direct	22, 479	147. 2	139. 0	123. 4	105. 9	91. 8	84. 5	69. 4	54. 0
Total basin	202, 691	75. 9	71. 4	62. 9	54. 4	28. 1	25. 1	18. 6	13. 4

TABLE No. 36.—*Decennial increase in population of the principal tributary basins of the Ohio River—Percentage change in total, urban and rural population, 1890–1900 and 1900–1910*

Basin	Percentage increase					
	Total		Urban		Rural	
	1890–1900	1900–1910	1890–1900	1900–1910	1890–1900	1900–1910
Allegheny	18. 2	22. 4	60. 7	54. 2	7. 6	10. 6
Monongahela	42. 0	44. 4	123. 8	102. 4	24. 9	22. 7
Beaver	16. 8	33. 8	47. 9	68. 2	[1] 0. 5	5. 0
Muskingum	6. 8	11. 2	3. 4	4. 2	[1] 1. 6	[1] 2. 0
Little Kanawha	18. 0	0. 0	----------	----------	18. 0	0. 0
Hocking	6. 0	15. 0	0. 1	44. 5	8. 2	5. 2
Kanawha	25. 0	26. 0	11. 2	7. 8	21. 0	21. 8
Guyandotte	17. 0	31. 2	----------	----------	17. 0	31. 2
Big Sandy	44. 4	45. 2	----------	----------	44. 4	42. 7
Scioto	11. 1	10. 3	32. 8	33. 1	[1] 0. 15	[1] 5. 5
Little Miami	[1] 0. 9	[1] 2. 8	13. 0	4. 7	[1] 2. 9	[1] 3. 9
Licking	10. 8	[1] 5. 1	13. 0	18. 2	10. 6	[1] 7. 4
Miami	5. 0	12. 5	27. 2	28. 6	[1] 8. 1	[1] 0. 5
Kentucky	13. 8	5. 5	26. 9	31. 2	11. 9	1. 2
Salt	3. 8	3. 4	2. 4	7. 9	3. 9	3. 1
Green	9. 0	3. 9	85. 2	58. 3	7. 3	1. 9
Wabash	15. 6	5. 3	57. 7	31. 8	4. 1	[1] 5. 6
Saline	6. 9	10. 5	----------	----------	6. 9	[1] 4. 8
Cumberland	15. 4	10. 2	12. 2	40. 5	15. 9	5. 1
Tennessee	14. 4	10. 7	36. 3	46. 4	12. 7	7. 2
Minor basins and Ohio River direct	16. 5	12. 6	28. 4	21. 8	4. 1	0. 8
Total basin	15. 63	13. 48	38. 12	35. 55	8. 28	4. 25

[1] Decrease.

TABLE NO. 37.—*Areas and population of the Ohio River Basin above designated points on the main river—Total and urban population for 1890, 1900, 1910, and estimated 1915*

[Data for: 1890, 1900, 1910 from Bureau of the Census; 1915, estimated July 1]

Point	Area	Population							
		Total				Urban			
		July 1, 1915 (estimated)	1910	1900	1890	July 1, 1915 (estimated)	1910	1900	1890
	Sq. mile								
Lower limits of Pittsburgh[1]	19, 010	2, 827, 500	2, 530, 707	1, 968, 020	1, 535, 977	1, 418, 300	1, 251, 307	862, 560	569, 022
Pennsylvania—Ohio State Line	23, 422	3, 652, 900	3, 248, 438	2, 481, 521	1, 958, 827	1, 866, 100	1, 626, 391	1, 067, 275	692, 440
Above Wheeling[2]	24, 531	3, 843, 200	3, 417, 408	2, 610, 101	2, 073, 941	1, 951, 500	1, 701, 764	1, 121, 083	730, 823
Above Muskingum River[3]	27, 414	4, 123, 100	3, 687, 919	2, 862, 892	2, 290, 942	2, 056, 000	1, 799, 482	1, 203, 757	795, 750
Including Muskingum River	35, 403	4, 772, 600	4, 304, 735	3, 417, 704	2, 810, 286	2, 323, 800	2, 034, 259	1, 368, 878	919, 003
Above Little Kanawha River[4]	35, 457	4, 800, 100	4, 327, 976	3, 432, 825	2, 822, 814	2, 343, 900	2, 052, 101	1, 380, 581	927, 411
Including Little Kanawha River	37, 738	4, 891, 200	4, 419, 161	3, 524, 046	2, 900, 147	2, 343, 900	2, 052, 101	1, 380, 581	927, 411
Above Hocking River	37, 869	4, 896, 800	4, 425, 162	3, 530, 838	2, 906, 694	2, 343, 900	2, 052, 101	1, 380, 581	927, 411
Including Hocking River	39, 096	5, 014, 700	4, 535, 495	3, 626, 800	2, 997, 182	2, 383, 700	2, 086, 675	1, 404, 505	951, 311
Above Kanawha River	40, 269	5, 073, 200	4, 597, 731	3, 694, 667	3, 061, 488	2, 390, 800	2, 093, 892	1, 411, 943	959, 248
Including Kanawha River	52, 342	5, 669, 000	5, 134, 350	4, 120, 678	3, 402, 337	2, 457, 500	2, 149, 883	1, 443, 398	974, 083
Above Guyandotte River	53, 303	5, 717, 700	5, 186, 036	4, 178, 071	3, 454, 360	2, 469, 400	2, 162, 318	1, 456, 875	982, 958
Including Guyandotte River	54, 962	5, 809, 400	5, 249, 801	4, 226, 682	3, 495, 901	2, 469, 400	2, 162, 318	1, 456, 875	982, 958
Above Big Sandy River	55, 907	5, 875, 200	5, 326, 024	4, 284, 721	3, 547, 420	2, 513, 000	2, 193, 479	1, 468, 798	993, 066
Including Big Sandy River	60, 126	6, 110, 000	5, 527, 636	4, 423, 473	3, 643, 490	2, 516, 500	2, 197, 040	1, 468, 798	993, 066
Above Scioto River[5]	61, 827	6, 251, 900	5, 660, 950	4, 540, 502	3, 741, 025	2, 571, 900	2, 245, 876	1, 508, 417	1, 020, 594
Including Scioto River	68, 356	6, 832, 200	6, 214, 065	5, 042, 073	4, 192, 312	2, 880, 400	2, 518, 721	1, 713, 376	1, 174, 827
Above Little Miami River	70, 518	6, 933, 100	6, 318, 585	5, 153, 434	4, 301, 644	2, 890, 400	2, 527, 621	1, 719, 799	1, 180, 185
Including Little Miami River	72, 300	7, 082, 600	6, 464, 137	5, 291, 411	4, 432, 868	2, 944, 800	2, 575, 910	1, 756, 495	1, 207, 272
Above Licking River[6]	72, 314	7, 174, 300	6, 551, 814	5, 371, 553	4, 500, 908	3, 035, 600	2, 662, 730	1, 835, 904	1, 274, 652
Including Licking River	75, 965	7, 355, 100	6, 737, 862	5, 567, 600	4, 677, 821	3, 057, 800	2, 683, 208	1, 853, 289	1, 290, 034
Above Miama River[7]	76, 231	7, 797, 300	7, 157, 269	5, 943, 796	5, 019, 514	3, 464, 300	3, 069, 975	2, 189, 137	1, 575, 621
Includin Miami River[7]	81, 627	8, 409, 000	7, 735, 067	6, 457, 216	5, 508, 688	3, 795, 700	3, 365, 885	2, 419, 313	1, 756, 548
Above Kentucky River	82, 633	8, 464, 000	7, 792, 446	6, 519, 141	5, 572, 048	3, 803, 900	3, 374, 225	2, 427, 284	1, 764, 761
Including Kentucky River	89, 692	8, 831, 300	8, 149, 894	6, 857, 877	5, 869, 655	3, 874, 400	3, 438, 017	2, 475, 901	1, 803, 059
Above Louisvile[8]	90, 484	8, 877, 700	8, 195, 963	6, 903, 368	5, 913, 391	3, 880, 900	3, 444, 951	2, 483, 736	1, 811, 995
Above Salt River	90, 926	9, 184, 200	8, 488, 192	7, 168, 511	6, 133, 167	4, 154, 900	3, 702, 663	2, 719, 869	2, 004, 849
Including Salt River	93, 777	9, 316, 100	8, 617, 796	7, 293, 798	6, 253, 892	4, 165, 700	3, 712, 299	2, 728, 804	2, 013, 574
Above Owensboro[9]	96, 517	9, 433, 500	8, 737, 574	7, 418, 213	6, 373, 171	4, 171, 300	3, 718, 404	2, 734, 366	2, 013, 574
Above Green River	97, 051	9, 478, 200	8, 781, 835	7, 461, 401	6, 411, 248	4, 193, 300	3, 738, 349	2, 750, 404	2, 023, 411
Including Green River	106, 205	9, 902, 800	9, 198, 119	7, 861, 922	6, 778, 804	4, 218, 700	3, 761, 207	2, 764, 849	2, 031, 214

Above Evansville [10]	106, 226	9, 903, 600	9, 199, 138	7, 863, 358	6, 780, 019	4, 218, 700	3, 761, 207	2, 764, 849	2, 031, 214
Above Wabash River	107, 204	10, 034, 500	9, 327, 186	7, 986, 137	6, 887, 370	4, 308, 700	3, 850, 594	2, 839, 260	2, 095, 510
Including Wabash River	139, 680	12, 338, 900	11, 571, 978	10, 117, 746	8, 731, 430	5, 216, 500	4, 671, 846	3, 462, 463	2, 490, 648
Above Saline River	139, 766	12, 343, 400	11, 576, 658	10, 122, 892	8, 734, 855	5, 216, 500	4, 671, 846	3, 462, 463	2, 490, 648
Including Saline River	140, 930	12, 409, 400	11, 639, 538	10, 179, 814	8, 788, 103	5, 227, 800	4, 680, 521	3, 462, 463	2, 490, 648
Above Cumberland River	142, 964	12, 490, 300	11, 722, 214	10, 265, 959	8, 865, 295	5, 235, 300	4, 684, 452	3, 465, 475	2, 490, 648
Including Cumberland River	160, 909	13, 398, 200	12, 587, 962	11, 051, 673	9, 546, 400	5, 403, 800	4, 841, 445	3, 577, 152	2, 590, 208
Above Tennessee River [11]	160, 993	13, 401, 500	12, 591, 482	11, 055, 588	9, 549, 728	5, 403, 800	4, 841, 445	3, 577, 152	2, 590, 208
Including Tennessee River	201, 601	15, 280, 100	14, 378, 697	12, 669, 505	10, 959, 874	5, 646, 600	5, 053, 555	3, 722, 012	2, 696, 485
Above mouth	202, 691	15, 381, 200	14, 474, 250	12, 754, 466	11, 029, 118	5, 694, 600	5, 098, 355	3, 760, 802	2, 723, 179

[1] Includes Pittsburgh.
[2] Wheeling not included.
[3] Includes Marrietta.
[4] Includes Parkersburg.
[5] Includes Portsmouth.
[6] Includes Newport and part of Cincinnati.
[7] Includes part of Cincinnati.
[8] Louisville not included.
[9] Owensboro not included.
[10] Evansville not included.
[11] Paducah not included.

TABLE No. 38.—*Density of population of the Ohio River Basin above designated points on the main river—Total, urban and rural population per square mile for 1890, 1900, 1910, and estimated 1915*

Point	Population per square mile											
	Total				Urban				Rural			
	1915	1910	1900	1890	1915	1910	1900	1890	1915	1910	1900	1890
Below Pittsburgh	148.7	133.1	103.6	80.8	74.6	65.8	45.4	29.9	74.1	67.3	58.2	50.9
Above Wheeling	156.7	139.3	106.4	84.6	79.6	69.4	45.7	29.8	77.1	69.9	60.7	54.8
Above Cincinnati including Little Miami River	98.0	89.4	73.2	61.3	41.0	35.6	24.3	16.6	57.0	53.8	48.9	44.7
Below Cincinnati and above Miami River	102.2	93.8	78.0	65.8	45.6	40.2	28.8	20.6	56.6	53.6	49.2	45.2
Above Louisville	98.1	90.6	76.3	65.3	43.0	38.1	27.5	20.0	55.1	52.5	48.8	45.3
Above Evansville	93.2	86.6	74.0	63.8	39.8	35.4	26.0	19.1	53.4	51.2	48.0	44.7
Above Cumberland River	87.4	82.0	71.8	61.9	36.8	32.8	24.2	17.3	50.6	49.2	47.6	44.6
Above Tennessee River	83.3	78.2	68.4	59.3	33.7	30.1	22.0	16.1	49.6	48.1	46.4	43.2
Above mouth	75.9	71.4	62.9	54.4	28.1	25.1	18.6	13.4	47.8	46.3	44.4	41.0

As is readily seen from these tables and figures, the population is decidedly more dense in the northern than in the southern portion of the watershed; and more dense in the eastern than in the western portion. Of the major tributary drainage areas shown in Tables 34 and 35, the most densely populated is the Beaver watershed, with 158 inhabitants per square mile. Next in order are the watersheds of the Monongahela (147 per square mile) the Miami (113 per square mile) and the Allegheny (101 per square mile). The greater density of population upon the northeastern part of the watershed is due to the greater industrial development, especially in the coal and oil fields. The greater density of rural population in these areas is due not to more intensive agricultural development, but rather to the greater concentration of population in small industrial communities which are classified as "rural."

Due to the greater concentration of population in the region around the upper part of the river, the density of population in the entire area above successive points on the main stream decreases from 157 per square mile above Wheeling to 76 per square mile at the mouth of the river, as shown in Table No. 38. Also, in passing downstream, the ratio of urban to total population steadily decreases. Thus, the urban population constitutes 51 per cent of the total on the watershed above Wheeling; 42 per cent of that above Cincinnati, and 37 per cent of the total above the mouth. It follows that, even in the absence of any natural agencies of purification, mere physical dilution would tend to decrease the concentration of pollution due to urban sewage in passing downstream from Pittsburgh to the mouth.

SEWERAGE

As the urban population which is of the most definite significance in relation to stream pollution is the population tributary to sewerage systems, it will be convenient, in the further analysis of the distribution of urban population, to add statistics as to sewerage. When this study was begun no complete statistics were available from any single source as to the population served by sewers in individual communities on the Ohio watershed. Unpublished records as to the sewerage of some communities were on file in the offices of the State health authorities in several States; and by courtesy of the State officials these were made available and have been freely used. For the most part, however, the data here presented were collected by engineers and medical officers of the Public Health Service in the course of a special survey made during the years 1914 and 1915. The localities from which information was thus collected at first-hand included all the urban communities of whatever size located directly upon the Ohio River, as listed in Table No. 40 below. In addition, a total of 133 communities situated upon tributary watersheds were visited, including all municipalities of 8,000 or more inhabitants, and a number of smaller size. The aggregate population of the communities visited on the Ohio and its tributaries is estimated, as of 1915, at 4,960,000, which is approximately 87 per cent of the entire urban population on the watershed.

In the communities visited information as to the extent of their sewerage systems was obtained from the local officials, supplemented to some extent by inspection, and, so far as possible, checked against the records of the State authorities. Public institutions and large industrial establishments situated in the vicinity of the surveyed cities, but not connected to the municipal sewerage systems, were also visited in order to obtain records of their sewerage. As to the small communities which were not visited, data were collected in part from the records of State health authorities, and in part from correspondence with local officials, leaving only a small residue to which it has been necessary to apply estimates without specific information.

The estimates of sewered population as finally compiled are by no means exact, chiefly because in many communities there are no exact records of the population tributary to sewers. The data are, however, as accurate as could be obtained without excessively laborious and expensive investigation, and are believed to be sufficiently exact for all the purposes of this study. In so far as they may be in error, it is considered more likely that they understate rather than overstate the sewered population.

Distribution of sewered population on the watershed.—A summary of sewered population upon the principal drainage areas of the Ohio watershed is presented in Table No. 39, along with statistics of urban

population, which are repeated from Table No. 34. The summary also shows the population tributary to sewage treatment plants in each area, but these figures will be discussed later.

TABLE NO. 39.—*Urban and sewered population of the principal tributary basins of the Ohio River—Statistics of urban, total sewered, and sewered population tributary to treatment plants (estimates as of July 1, 1915)*

Basin	Urban population (1915)	Sewered population		Per cent of urban population sewered	Per cent of sewered population tributary to treatment plants
		Total	Tributary to treatment plants		
Allegheny	416,600	347,000	14,400	83.2	4.1
Monongahela	429,800	370,100	800	86.1	0.2
Beaver	302,600	220,000	25,000	72.8	11.3
Muskingum	267,700	173,500	99,700	64.8	57.4
Little Kanawha	None.	None.	None.		
Hocking	39,700	18,000	None.	45.4	None.
Kanawha	66,800	52,900	1,200	79.4	2.3
Guyandotte	None.	None.	None.	None.	
Big Sandy	3,600	[1] 6,900	None.	[1] 192	None.
Scioto	308,500	248,200	230,400	80.5	92.7
Little Miami	16,300	6,200	4,300	38.0	69.4
Licking	22,200	9,500	4,800	42.7	50.6
Miami	321,500	180,400	11,500	56.0	6.4
Kentucky	70,500	24,500	2,400	34.8	10.0
Salt	10,000	4,300	1,800	43.0	41.7
Green	25,500	2,300	1,100	9.0	47.8
Wabash	907,800	501,200	49,700	55.2	9.9
Saline	11,300	1,200	None.	10.6	None.
Cumberland	168,500	87,200	4,400	51.7	5.0
Tennessee	242,800	172,700	4,700	71.0	2.7
Minor basins and Ohio River direct [2]	2,062,900	[3] 1,680,500	[4] 27,700	81.3	0.7
Total	5,694,600	4,106,600	483,900	72.1	11.8

[1] Sewered population on Big Sandy includes a number of small communities classed as "rural," hence it exceeds the urban population.
[2] Includes Chartiers Creek, Little Beaver, Raccoon Creek, Mill Creek (at Cincinnati), and other minor drainage areas.
[3] Sewered population includes 38,800 on Chartiers Creek (Pittsburgh district), 10,000 on Little Beaver, 2,000 on Raccoon Creek, and 2,800 on small tributaries.
[4] Population tributary to disposal plants includes 17,100 on Chartiers Creek and 7,000 on Little Beaver.

According to this summary the sewered population on the entire watershed amounts to 4,106,600, which is 72 per cent of the urban population. Actually, something less than this percentage of the population resident in urban communities is served by sewers, since the sewered population given in the above table includes that of some communities which are classed as rural; but this number is hardly enough to make a significant difference in the total. The densities of sewered population in the major drainage areas of the Ohio Basin are indicated in Figure No. 13, from which it may be seen that the distribution of sewered population is generally similar to that of urban population. (Compare Figure 11.) The greatest densities are in the area around the confluence of the Allegheny and Monongahela Rivers, which includes the Pittsburgh metropolitan district; and in the central area which includes the Cincinnati and Louisville metropolitan districts.[7] Of the major tributary drainage areas,

[7] As shown in Figures 11 and 13 the combined population of the Cincinnati and Louisville metropolitan districts is distributed over the entire area which drains directly to the Ohio River between these two cities. Actually this population is concentrated in two small areas, around Cincinnati and Louisville, respectively; and the population on the intervening drainage area is quite sparse.

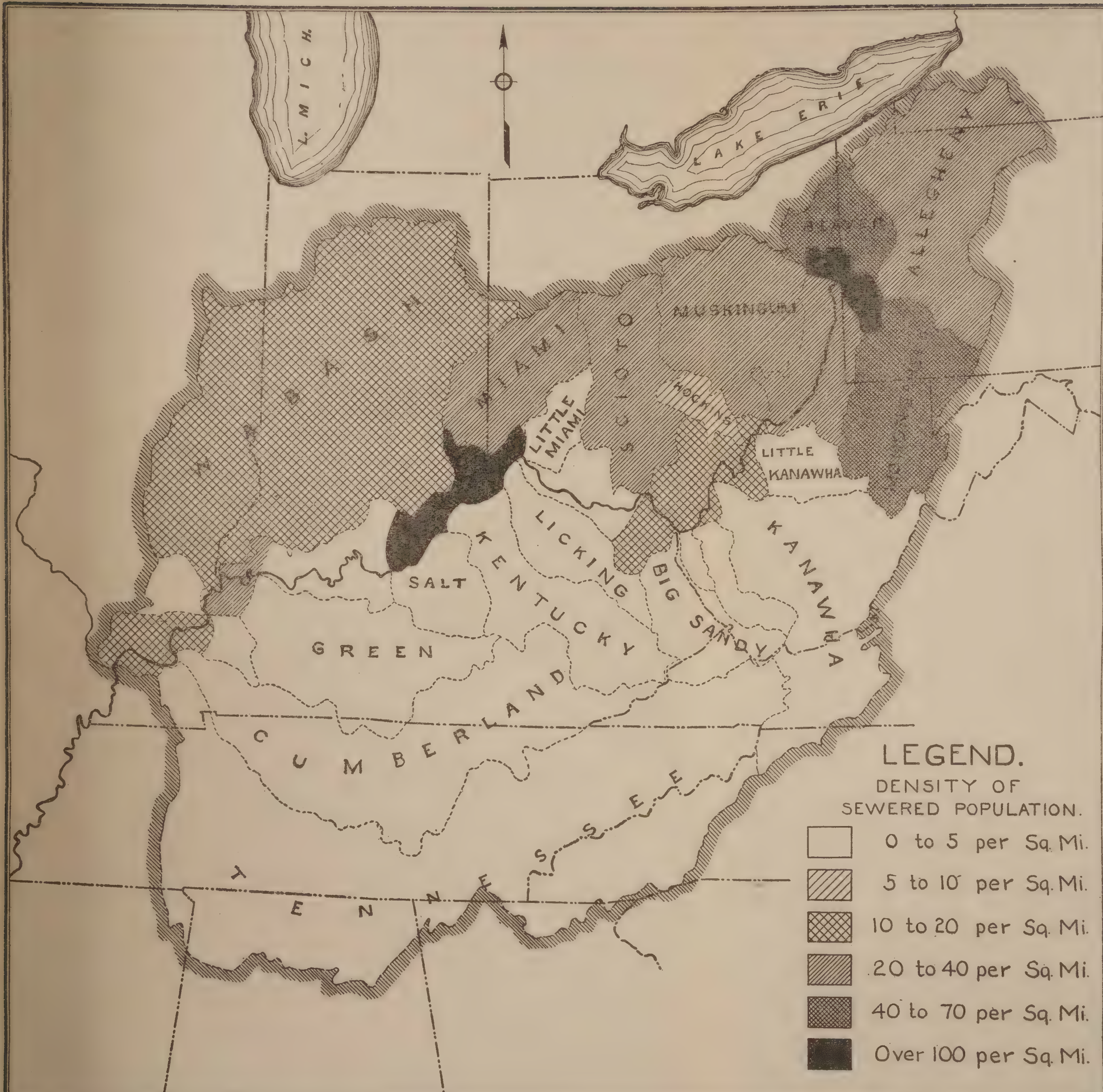

Fig. 13.—Density of sewered population on the Ohio River watershed by tributary drainage areas, 1915

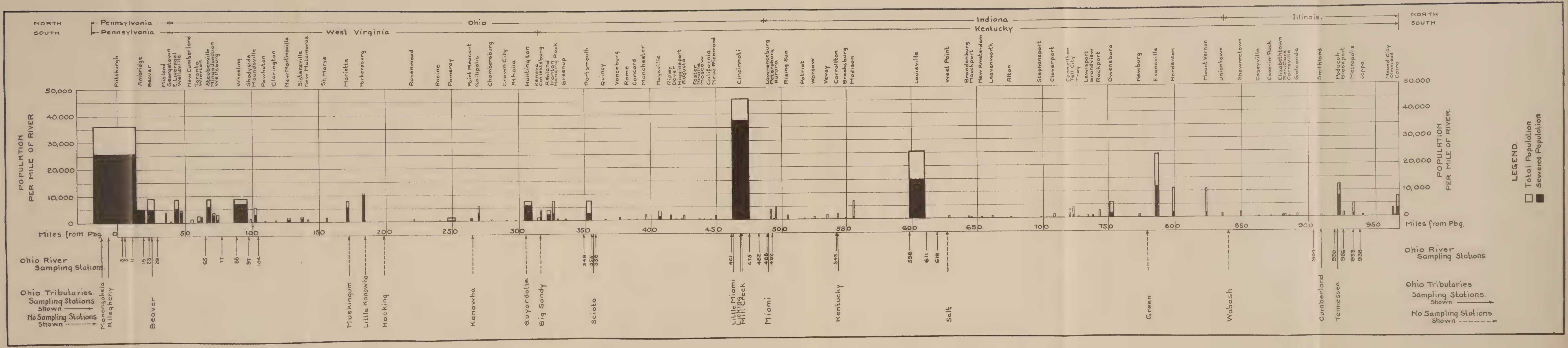

FIG. 14.—Distribution of total and sewered populations in incorporated communities situated directly upon the Ohio River; showing relation to tributary junctions and to sampling stations. Populations as of July 1, 1915

those having the greatest densities of sewered population are the watersheds of the Beaver, Monongahela, Scioto, and Miami Rivers, in the order named.

Distribution of urban and sewered population directly upon the Ohio River.—A noteworthy feature of the distribution of urban population on the Ohio watershed is that it is concentrated to a remarkable extent in communities situated directly upon the Ohio River itself. Thus, as shown in Table No. 39, the communities situated directly upon the Ohio[8] comprise about 36 per cent of the urban population and a little over 40 per cent of the sewered population of the entire watershed. As the urban and sewered populations located immediately upon the main stream are of special importance in relation to this study, their distribution is shown in detail in Table No. 40, and indicated graphically in Figure 14. This figure also shows the location of the stations on the Ohio River from which samples were collected for chemical and biological examinations; and Table No. 41, summarizes the urban and sewered populations between consecutive sampling stations. This latter table is, however, inserted chiefly for reference in connection with the results of chemical and bacteriological examinations presented in Sections V and VI.

TABLE No. 40.—*Population of urban communities situated upon the banks of the Ohio River—Incorporated places of 2,500 or more inhabitants in 1910, with distance by river from Pittsburgh and population in 1890, 1900, 1910, estimated 1915, and estimated sewered in 1915*

Municipality	State	Distance from Pittsburgh	Population				Total sewered population, 1915
			July 1, 1915 (estimated) [a]	1910 [b]	1900 [b]	1890 [b]	
		Miles.					
Pittsburgh metropolitan district.[c]	Pa.	0	1,153,108	1,042,855	792,968	543,516	[d] 827,300
Ambridge	Pa.	16	(e)	5,205			4,900
Freedom	Pa.	23	(e)	3,060	1,783	704	2,700
Monaca	Pa.	25	(e)	3,376	2,008	1,494	1,900
Rochester	Pa.	25	(e)	5,903	4,688	3,649	3,500
Beaver	Pa.	26	(e)	3,456	2,348	1,552	2,300
Additional tributary to sewers, Pittsburgh to Pennsylvania.—Ohio State line:							[f] 42,100
Chester	W. Va.	43	(e)	3,184			2,000
East Liverpool	Ohio	44	22,231	20,387	16,485	10,956	10,200
Wellsville	Ohio	47	(e)	7,769	6,146	5,247	6,000
Toronto	Ohio	60	(e)	4,271	3,526	2,536	1,400
Additional tributary to sewers, Pennsylvania.—Ohio State line to Steubenville:							7,600
Steubenville	Ohio	68	26,631	22,391	14,349	13,394	12,900
Mingo Junction	Ohio	71	(e)	4,049	2,954	1,856	1,400
Wellsburg	W. Va.	74	(e)	4,189	2,588	2,235	1,600
Martins Ferry	Ohio	88	9,857	9,133	7,760	6,250	6,100

[a] Estimates from U. S. Census Bulletin No. 138.
[b] Population by Federal census, Apr. 15, 1910, June 1, 1900, and June 1, 1890, respectively.
[c] Composition of Pittsburgh metropolitan district given in Thirteenth Census of the United States, 1910, Vol. X, "Manufactures."
[d] Allowance made for night soil discharged to sewers.
[e] Not estimated separately.
[f] Includes New Brighton and Beaver Falls.

[8] Including the drainage areas of such small tributaries as Chartiers Creek in the Pittsburgh metropolitan area; Wheeling Creek; Mill Creek in the Cincinnati district, etc.

TABLE No. 40.—*Population of urban commvnities situated upon the banks of the Ohio River—Incorporated places of 2,500 or more inhabitants in 1919, with distance by river from Pittsburgh and population in 1890, 1900, 1910, estimated 1915, and estimated sewered in 1915*—Continued

Municipality	State	Distance from Pittsburgh	Population				Total sewered population, 1915
			July 1, 1915 (estimated)	1910	1900	1890	
		Miles.					
Additional tributary to sewers, Steubenville to Wheeling:							13, 100
Wheeling	W. Va	90	43, 097	41, 641	38, 878	34, 522	31, 000
Bridgeport	Ohio	90	(e)	3, 974	3, 963	3, 369	d 1, 600
Benwood	W. Va	94	(e)	4, 976	4, 511	2, 934	1, 800
Bellaire	Ohio	94	14, 122	12, 946	9, 912	9, 934	9, 200
McMechen	W. Va	96	(e)	2, 921	1, 465	427	2, 000
Additional tributary to sewers, Wheeling to Moundsville:							13, 900
Moundsville	W. Va	101	10, 793	8, 918	5, 362	2, 688	5, 300
Sistersville	W. Va	137	(e)	2, 684	2, 979	469	3, 700
Marietta	Ohio	171	14, 699	12, 923	13, 348	8, 273	10, 200
Additional tributary to sewers, Moundsville to Muskingum River:							3, 200
Parkersburg	W. Va	184	20, 165	17, 842	11, 703	8, 408	20, 000
Pomeroy	Ohio	249	(e)	4, 023	4, 639	4, 726	800
Middleport	Ohio	252	(e)	3, 194	2, 799	3, 211	1, 000
Additional tributary to sewers, Muskingum River to Kanawha River:							1, 200
Gallipolis	Ohio	269	(e)	5, 560	5, 432	4, 498	2, 700
Huntington	W. Va	308	43, 571	32, 863	13, 373	10, 108	30, 900
Additional tributary to sewers, Kanawha River to Big Sandy River:							2, 500
Catlettsburg	Ky	317	(e)	3, 520	3, 081	1, 374	1, 200
Ashland	Ky	322	9, 683	8, 688	6, 800	4, 195	5, 000
Ironton	Ohio	327	13, 819	13, 147	11, 868	10, 939	4, 800
Portsmouth	Ohio	355	28, 126	23, 481	17, 870	12, 394	7, 000
Additional tributary to sewers, Big Sandy River to Scioto River:							5, 800
Maysville	Ky	407	(e)	6, 141	6, 423	5, 358	2, 400
Additional tributary to sewers, Scioto River to Little Miami River.							400
Cincinnati metropolitan district: g	Ohio & Ky.	468	594, 733	563, 804	495, 979	436, 461	494, 300
Lawrenceburg	Ind	491	(e)	3, 930	4, 326	4, 284	0
Aurora	Ind	495	(e)	4, 410	3, 645	3, 929	600
Madison	Ind	555	(e)	6, 934	7, 835	8, 936	800
Additional tributary to sewers, Miami River to Louisville:							300
Louisville metropolitan district. h	Ky & Ind	601	306, 183	286, 158	259, 856	233, 544	d 179, 800
Tell City	Ind	723	(e)	3, 369	2, 680	2, 094	800
Rockport	Ind	743	(e)	2, 736	2, 882	2, 314	300
Owensboro	Ky	752	17, 498	16, 011	13, 189	9, 837	5, 100
Additional tributary to sewers, Salt River to Green River:							900
Evansville	Ind	787	72, 125	69, 647	59, 007	50, 756	36, 200
Henderson	Ky	798	12, 072	11, 452	10, 272	8, 835	3, 200
Mt. Vernon	Ind	823	(e)	5, 563	5, 132	4, 705	1, 800
Additional tributary to sewers, Green River to Tennessee River:							800
Paducah	Ky	924	24, 506	22, 760	19, 446	12, 797	d 15, 700
Metropolis	Ill	933	(e)	4, 655	4, 069	3, 573	1, 800
Mound City	Ill	962	(e)	2, 837	2, 705		0
Cairo	Ill	967	15, 593	14, 548	12, 566	10, 324	6, 200
Total			2, 530, 500	2, 367, 484	1, 925, 588	1, 513, 615	1, 863, 200

NOTE.—In the urban population for 1890 and 1900 are included all communities incorporated prior to these respective dates, and having, in 1910, 2,500 inhabitants or more.

[d] Allowance made for night soil discharged to sewers.

[e] Not estimated separately.

[g] Composition of Cincinnati metropolitan district given in Thirteenth Census of the United States, 1910, Vol. X, "Manufactures."

[h] Composition of Louisville metropolitan district given in Thirteenth Census of the United States, 1910, Vol. X, "Manufactures."

TABLE NO. 41.—*Urban and sewered population situated upon the banks of the Ohio River between consecutive sampling stations—Urban population for 1890, 1900, 1910, estimated 1915, and estimated sewered population 1915*

Between sampling stations	Urban population				Sewered population 1915, (estimated) [1]
	July 1, 1915 (estimated)	1910	1900	1890	
Monongahela 12, Allegheny 7, and Ohio 3 [2]	819,400	742,818	565,959	388,330	710,500
Ohio 3, and Ohio 11 [2]	44,800	35,082	17,175	3,902	35,200
Ohio 11 and Ohio 19 [2]	14,900	13,242	3,930	2,997	35,700
Ohio 19 and Ohio 23					8,900
Ohio 23 and Ohio 29	18,300	15,795	10,827	7,399	[3] 16,700
Ohio 29 and Ohio 65	39,000	35,611	26,157	18,739	31,300
Ohio 65 and Ohio 77	36,300	30,629	19,891	17,485	24,500
Ohio 77 and Ohio 88	9,900	9,133	7,760	6,250	10,600
Ohio 88 and Ohio 97	69,200	66,458	58,729	51,186	59,500
Ohio 97 and Ohio 104	10,800	8,918	5,362	2,688	5,300
Ohio 104 and Ohio 349	120,900	104,444	76,022	56,201	89,800
Ohio 349 and Ohio 355	28,100	23,481	17,870	12,394	10,200
Ohio 355 and Ohio 358					0
Ohio 358 and Ohio 461	6,000	6,141	6,423	5,358	2,800
Ohio 461 and Ohio 475 [4]	594,700	563,804	495,979	463,461	494,300
Ohio 475 and Ohio 482					0
Ohio 482 and Ohio 488					0
Ohio 488 and Ohio 492	3,700	3,930	4,326	4,284	0
Ohio 492 and Ohio 543	4,900	4,410	3,645	3,929	900
Ohio 543 and Ohio 598	6,500	6,934	7,835	8,936	800
Ohio 598 and Ohio 611 [4]	306,200	286,158	259,856	233,554	179,800
Ohio 611 and Ohio 619					0
Ohio 619 and Ohio 904	113,900	108,778	93,152	78,541	49,100
Ohio 904 and Ohio 920					0
Ohio 920 and Ohio 926	24,500	22,760	19,446	12,797	15,700
Ohio 926 and Ohio 933	5,000	4,655	4,069	3,573	1,800
Ohio 933 and Ohio 967	18,500	17,385	15,271	10,324	6,200

NOTE.—Under urban population are included all incorporated places having, in 1910, 2,500 or more inhabitants, except that communities incorporated, between 1890 and 1900 or between 1900 and 1910, and having a population less than 2,500 in 1890 or 1900, are omitted from the 1890 and 1900 population groups.

[1] Includes large industrial plants sewered directly to the river if same are not in metropolitan district.
[2] Part of Pittsburgh metropolitan district. Not including unincorporated communities nor portion of district above M-12 and A-7.
[3] Total Cincinnati metropolitan district.
[4] Total Louisville metropolitan district.

As shown in Table No. 40 and Figure 14, the population along the Ohio River is comprised chiefly in the metropolitan districts [9] of Pittsburgh, at the confluence of the Allegheny and Monongahela Rivers; Cincinnati, 465 miles downstream; and Louisville, 600 miles below Pittsburgh. The metropolitan district of Pittsburgh furnishes about 56 per cent, that of Cincinnati about 29 per cent, and that of Louisville about 15 per cent of the entire urban population on the river. To the sewered population they contribute, respectively, 55, 33, and 12 per cent.

It may be seen from Figure 14 that the urban population not comprised within these metropolitan districts is more thickly distributed along the first 100 miles below Pittsburgh than in any other part of the river's course. It is likewise in this region that the most rapid increase in urban population has taken place since 1890, with

[9] The term "metropolitan district," as used here and elsewhere in this report conforms to the definition given by the U. S. Census Bureau; that is, it includes, in addition to the population within the limits of the central city, the population in "adjoining communities which may be considered as intimately associated with the urban center." The term is used only in connection with cities of more than 200,000 population. The metropolitan districts of Pittsburgh, Cincinnati, and Louisville are as defined in the Abstract of the Thirteenth Census of the United States, 1910, pp. 61-62.

the result that the center of urban population has moved steadily upstream. Thus, in 1890, the midpoint of urban population resident directly upon the banks of the river was at Cincinnati, 465 miles below Pittsburgh; in 1900 this midpoint had advanced to Gallipolis, 269 miles below Pittsburgh; while by 1910, a further advance had been made to Wheeling, only 90 miles below Pittsburgh. It is probable that this advance will continue, due to increased industrial activity in the upper watershed, a consideration that is of some importance from the standpoint of future pollution.

Distribution of urban and sewered population by distances from stated points.—Due to the action of agencies of natural purification, the pollution which any given unit of population contributes to the river system which receives its drainage, diminishes as distance from the source increases. It is, therefore, made the basis of classification in Table No. 42, following. In this table the urban population, as of 1910 and 1915, and the sewered population as of 1915, are distributed on each watershed according to distance by water from the mouth of the tributary.[10]

TABLE No. 42.—*Urban and sewered population of principal tributary basins of the Ohio River, arranged by 50-mile zones from the mouths of the respective tributaries*

[Urban population 1910, estimated 1915; estimated sewered 1915, and sewered to disposal plants, 1915]

Drainage basin	Distance zone from mouth	Urban population		Total sewered population	
		July 1, 1915 (estimated)	U. S. Census, 1910	1915 (estimated)	Sewered to disposal plant
	Miles				
Allegheny River	0– 50	88, 302	77, 431	68, 600	0
	50–100	24, 511	21, 052	27, 500	8, 500
	100–150	177, 103	153, 309	127, 600	1, 700
	150–200	36, 780	30, 852	30, 400	1, 500
	200–250	86, 844	78, 993	83, 900	2, 700
	250–300	3, 039	3, 100	9, 000	0
Monongahela River	0– 50	298, 495	250, 254	246, 100	800
	50–100	65, 596	52, 501	56, 400	0
	100–150	38, 209	27, 886	34, 600	0
	150–200	27, 459	22, 024	33, 000	0
Chartiers Creek	0– 50	45, 655	39, 804	38, 800	17, 100
Beaver River	0– 50	254, 962	210, 069	182, 200	2, 000
	50–100	29, 279	25, 934	22, 200	7, 400
	100–150	18, 339	15, 083	15, 600	15, 600
Little Beaver River	0– 50	19, 326	18, 229	10, 000	7, 000

[10] These summaries are made up from detailed tabulations showing the population of each urban community and its approximate distance from the Ohio River. As these detailed tabulations are voluminous, and of limited interest, they are not included in this report, but are kept on file by the Bureau of the Public Health Service and are available for reference.

TABLE No. 42.—*Urban and sewered population of principal tributary basins of the Ohio River arranged by 50-mile zones from the mouths of the respective tributaries*—Continued

Drainage basin	Distance zone from mouth	Urban population		Total sewered population	
		July 1, 1915 (estimated)	U. S. Census, 1910	1915 (estimated)	Sewered to disposal plant
	Miles				
Muskingum River	0– 50	----------	----------	1, 200	0
	50–100	34, 590	31, 054	12, 200	0
	100–150	43, 299	37, 950	20, 800	0
	150–200	169, 699	150, 189	125, 900	90, 200
	200–250	20, 148	15, 584	13, 400	9, 500
Little Kanawha River	0–150	0	0	0	0
Hocking River	0– 50	21, 453	18, 922	11, 600	0
	50–100	18, 266	15, 652	6, 400	0
Kanawha River	0– 50	0	0	0	0
	50–100	28, 822	22, 996	30, 400	0
	100–150	0	0	700	0
	150–200	9, 744	9, 744	7, 400	0
	200–250	25, 132	20, 197	12, 800	1, 200
	250–300	3, 081	3, 054	1, 600	0
Raccoon Creek	0– 50	0	0	0	0
	50–100	6, 258	6, 875	2, 000	0
Guyandotte River	0–100	0	0	0	0
Big Sandy River	0– 50	----------	----------	300	0
	50–100	3, 561	3, 561	5, 000	0
	100–150	0	0	1, 600	0
Scioto River	0– 50	----------	----------	0	0
	50–100	27, 816	26, 720	9, 600	1, 000
	100–150	229, 872	200, 842	207, 100	203, 600
	150–200	50, 800	45, 283	31, 500	25, 800
Little Miami River	0– 50	2, 607	2, 698	1, 800	0
	50–100	13, 664	13, 197	4, 400	4, 300
Licking River	0– 50	0	0	0	0
	50–100	10, 307	9, 462	4, 700	0
	100–150	11, 927	11, 088	4, 800	4, 800
Miami River	0– 50	39, 655	35, 279	15, 000	0
	50–100	176, 321	162, 170	115, 200	5, 400
	100–150	96, 498	90, 223	46, 100	2, 200
	150–200	9, 076	8, 238	4, 100	3, 900
Kentucky River	0– 50	0	0	0	0
	50–100	55, 591	50, 097	21, 900	1, 000
	100–150	14, 942	13, 695	2, 100	900
	150–200	0	0	500	500
Salt River	0– 50	0	0	200	0
	50–100	10, 006	9, 636	4, 100	1, 800
Green River	0– 50	0	0	0	0
	50–100	8, 847	7, 511	1, 200	0
	100–150	0	0	0	0
	150–200	13, 083	12, 284	0	0
	200–250	3, 536	3, 063	1, 100	1, 100

TABLE No. 42.—*Urban and sewered population of principal tributary basins of the Ohio River, arranged by 50-mile zones from the mouths of the respective tributaries*—Continued

Drainage basin	Distance zone from mouth	Urban population		Total sewered population	
		July 1 1915 (estimated)	U. S. Census, 1910	1915 (estimated)	Sewered to disposal plant
	Miles				
Wabash River	0– 50	2,781	2,833	1,500	0
	50–100	26,105	23,824	13,000	4,900
	100–150	54,978	48,368	18,300	3,300
	150–200	89,330	78,431	40,500	6,400
	200–250	47,406	42,414	18,400	6,400
	250–300	127,287	116,360	64,700	8,500
	300–350	359,895	319,806	237,000	20,200
	350–400	160,904	151,458	91,000	0
	400–450	35,223	34,265	16,800	0
	450–500	3,850	3,493	0	0
Saline River	0– 50	11,327	8,675	1,200	0
Cumberland River	0– 50	0	0	0	0
	50–100	3,258	3,015	1,000	0
	100–150	19,093	17,967	5,400	2,400
	150–200	115,978	110,364	72,500	0
	200–250	3,315	2,924	2,200	2,000
	250–300	9,594	8,338	500	0
	300–500	0	0	0	0
	500–550	8,272	7,080	800	0
	550–600	0	0	1,800	0
	600–650	8,962	7,305	3,000	0
Tennessee River	0– 50	0	0	0	0
	50–100	4,863	3,881	1,000	500
	100–150	0	0	400	0
	150–200	0	0	0	0
	200–250	21,909	20,632	5,700	0
	250–300	15,022	13,215	8,000	0
	300–350	14,169	13,978	11,600	0
	350–400	3,240	3,049	3,800	2,400
	400–450	58,576	44,604	50,000	0
	450–500	0	0	400	0
	500–550	13,363	12,270	4,100	0
	550–600	3,392	3,392	700	0
	600–650	47,942	44,288	39,000	0
	650–700	4,552	4,007	2,500	1,800
	700–750	23,592	21,352	27,400	0
	750–800	29,092	24,715	16,100	0
	800–850	3,086	2,727	2,000	0
Small streams	0– 50	15,011	13,394	2,800	0
	50–100	4,415	3,931	0	0

A more comprehensive summary is presented in Table No. 43, which shows the distribution, according to distance, of the entire sewered population on the watershed above certain points on the Ohio River, including the population on tributaries as well as that on the main stream. These distributions above Cincinnati, Louisville, and Paducah, respectively, are illustrated in Figures 15, 16, and 17.

FIG. 15.

GRAPHICAL REPRESENTATION OF THE DISTRIBUTION OF URBAN POPULATION IN 1915 ON THE OHIO RIVER AND ITS TRIBUTARIES IN 50 MILE ZONES ABOVE CINCINNATI, OHIO

Distances measured by water.

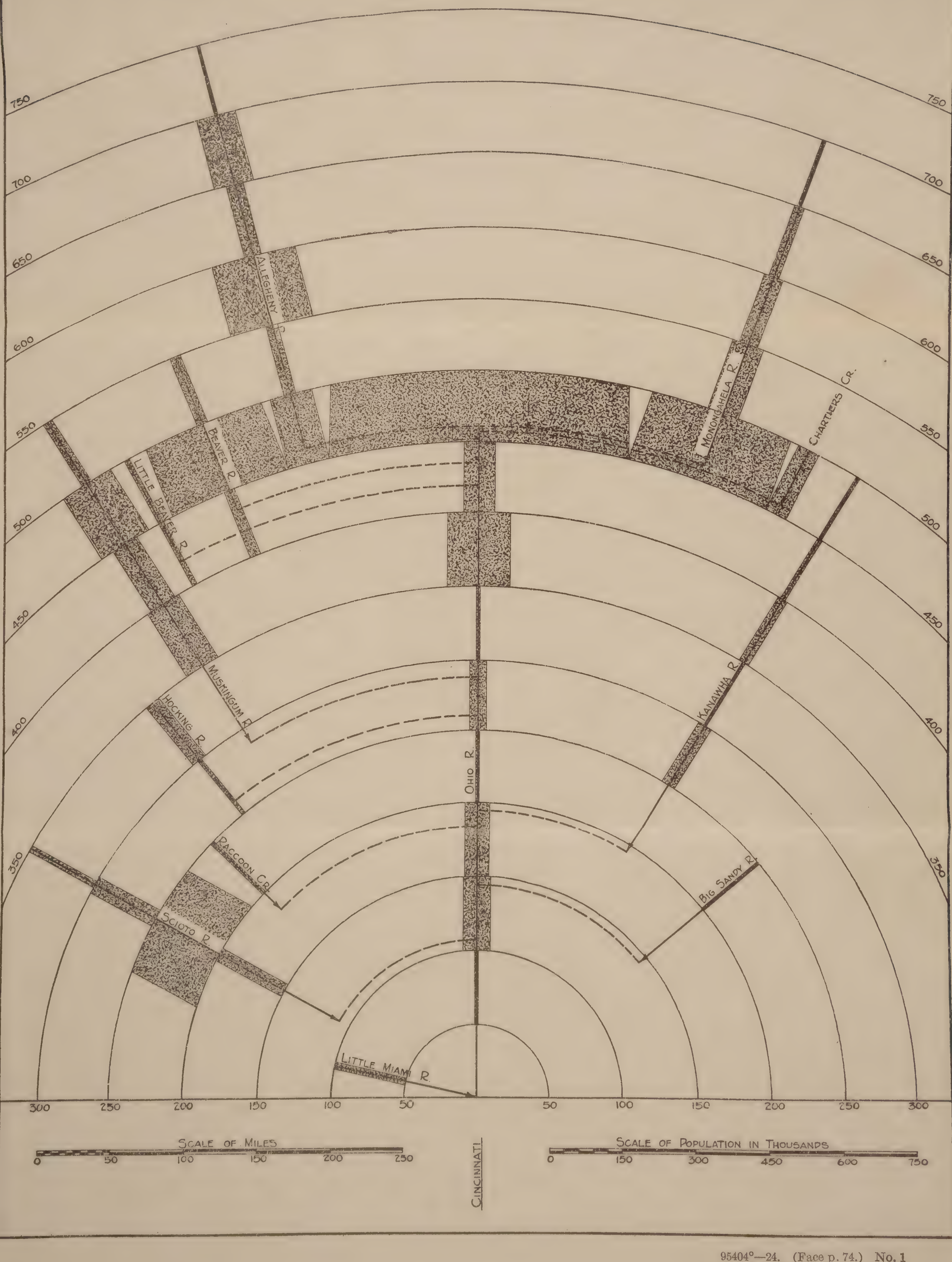

Fig. 16.

GRAPHICAL REPRESENTATION OF THE DISTRIBUTION OF URBAN POPULATION IN 1915 ON THE OHIO RIVER AND ITS TRIBUTARIES IN 50 MILE ZONES ABOVE LOUISVILLE, KY

Distances measured by water

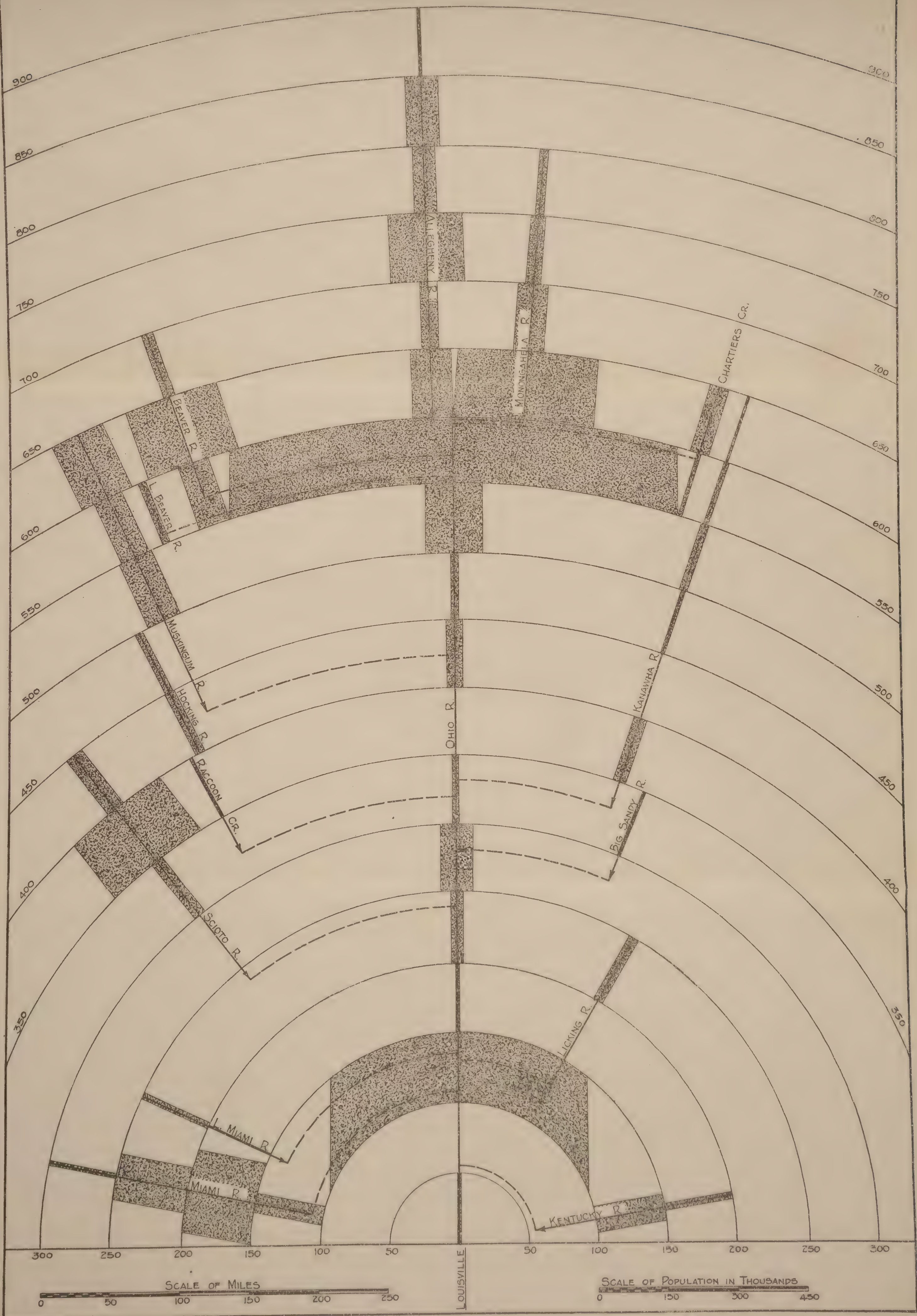

Fig. 17.

GRAPHICAL REPRESENTATION OF THE DISTRIBUTION OF URBAN POPULATION IN 1915 ON THE OHIO RIVER AND ITS TRIBUTARIES IN 50 MILE ZONES ABOVE PADUCAH, KY.

Distances measured by water.

TABLE No. 43.—*Sewered population of the Ohio River Basin by 50-mile zones by water above designated points on the main river*

Distance zone	Sewered population by zones above—						
	Sampling station No. 3 including Pittsburgh	Wheeling	Portsmouth	Cincinnati	Louisville	Paducah	Mouth of Ohio
Miles							
0-50	858, 800	51, 700	47, 100	1, 900	800	0	23, 700
50-100	83, 900	782, 100	9, 000	7, 100	200	6, 200	0
100-150	162, 200	461, 500	32, 400	32, 300	532, 000	51, 200	6, 200
150-200	63, 400	132, 100	44, 400	244, 700	121, 800	15, 600	51, 200
200-250	83, 900	125, 900	25, 200	41, 300	70, 700	101, 300	99, 800
250-300	9, 000	37, 000	141, 100	63, 200	51, 200	49, 200	19, 700
300-350		83, 900	138, 600	32, 200	20, 400	247, 800	54, 900
350-400		9, 000	1, 232, 500	140, 100	245, 400	61, 300	242, 400
400-450			116, 500	131, 100	72, 100	294, 400	245, 900
450-500			162, 200	1, 186, 400	26, 600	598, 100	629, 600
500-550			63, 400	153, 900	138, 400	143, 700	90, 500
550-600			83, 900	149, 400	774, 000	75, 000	167, 000
600-650			9, 000	80, 000	604, 100	84, 700	45, 900
650-700				62, 000	106, 900	24, 600	89, 000
700-750				38, 100	162, 200	272, 500	216, 400
750-800				9, 000	63, 400	74, 300	121, 400
800-850					83, 900	105, 600	49, 100
850-900					9, 000	95, 500	139, 000
900-950						795, 900	127, 300
950-1,000						585, 600	1, 159, 200
1,000-1,050						142, 800	217, 700
1,050-1,100						124, 900	124, 100
1,100-1,150						62, 600	73, 900
1,150-1,200						41, 100	65, 600
1,200-1,250						9, 000	38, 100
1,250-1,300							9, 000
Total	1, 261, 200	1, 683, 200	2, 105, 300	2, 372, 700	3, 083, 100	4, 062, 900	4, 106, 600

SEWAGE TREATMENT

In the course of the survey of sewerage in communities on the Ohio River watershed data were also collected regarding the construction and operation of sewage-disposal plants. So far as could be ascertained a total of 83 municipal sewage-disposal plants were in operation during 1915 on the entire watershed, treating the sewage of 483,900 people, which is about 11.8 per cent of the entire sewered population (4,106,600) on the watershed.

The largest disposal plants were those at Columbus, Ohio, serving a population of about 200,000, and at Canton, Ohio, serving 49,000 people. With these exceptions the municipal sewage treatment plants on the Ohio watershed up to 1915 were all serving small population groups. Consequently only 24 of the 80 plants were inspected in the survey of the watershed, the remainder being located in the smaller towns of less than 8,000 inhabitants, which were not included in the itinerary of the field parties. However, the 24 plants visited were serving a population of some 360,000, which is about 75 per cent of the total tributary to disposal plants and fairly complete data concerning the plants not visited were available from the State health authorities and local officials.

The distribution of the population served by sewage-treatment plants on the major subdivisions of the Ohio watershed is shown in Table No. 39. The only watersheds having large sewered populations of which any considerable proportion is tributary to disposal plants are those of the Scioto and Muskingum Rivers, which contribute 68 per cent of the total served by disposal plants. On several other watersheds, where the total urban population is less than 10,000, the small communities having sewage-treatment plants constitute more than 40 per cent of the total urban population. Of the communities discharging sewage directly into the main stream of the Ohio River none makes use of any sewage treatment, although disposal plants treating the sewage of 27,700 persons are located on the drainage areas of small streams which empty directly into the Ohio and are classified with the main stream in Table No. 39. A majority of the sewage-treatment plants on the watershed are located in Ohio and Pennsylvania, 34 in the former and 14 in the latter State.

The classification of the 80 sewage-disposal plants on the watershed, according to type and population served, is shown in Table No. 44, which follows:

TABLE No. 44.—*Character of sewage treatment on the Ohio River watershed—Summary of municipal sewage-treatment plants of various types and of total populations served*

Type of plant	Number in operation	Population served
Septic and settling tanks	31	61,000
Imhoff tanks	3	14,300
Tanks, followed by:		
Intermittent sand filters	21	42,100
Contact beds	14	45,800
Sprinkling filters	7	228,500
Contact beds and sprinkling filters	1	5,000
Contact beds and intermittent sand filters Sprinkling filters and intermittent sand filters	5	35,100
Chemical precipitation	1	[1] 52,100
Total	83	483,900

[1] Imhoff tank and contact filters installed during 1915–16, subsequent to survey.

Of the sewage-treatment plants inspected but few were found to be delivering effluents which could be considered satisfactory, and in a considerable number of instances the effluents were little better than the raw sewage. Some plants were found to be operating only a part of the time; others were by-passing a part of the sewage, while still others were so seriously overloaded that satisfactory treatment was impossible. The inspected plants which were delivering fairly satisfactory effluents were serving an aggregate population of only 43,800. Plants not inspected but presumably operating efficiently increase the population served by treatment plants producing fairly satisfactory effluents to a total of 97,000. Of the remaining plants, a very considerable proportion were of such low efficiency as

to have but little influence in reducing the pollution of the watercourses. Since the population of 97,000 served by effective treatment plants constitutes only 2 per cent of the total sewered population on the Ohio watershed, it must be concluded that in 1915 the net influence of sewage treatment was negligible so far as pollution of the Ohio River is concerned, although the more efficient plants were undoubtedly of value in the reduction or elimination of local nuisances. The failure of most of the plants to yield satisfactory results was due more to lack of attention in operation, and in some instances to inadequate capacity, than to fundamental faults in design.

DOMESTIC SEWAGE

Ratios of constituents to sewered population.—During recent years a number of different observers have made long-continued studies of the volume and composition of the combined sewage (i. e., sanitary sewage and storm water) from various sewered urban areas of known population. Such studies of the sewage from residential communities, where industrial wastes are a small item, have furnished a basis for calculating the ratios between the number of people contributing to a sewerage system and the average daily discharge of wastes in terms of the weights of such constituents and indices as are ordinarily determined in the physical and chemical examination of sewage. The ratios of sewered population to various sewage constituents as thus calculated have varied rather widely in different studies, and are probably at best of no great accuracy, so that there is no close agreement in standard references as to the average or modal ratios. The estimates given in Table No. 45 are based upon data from a number of different sources and are considered to be fairly representative values for the combined sewage of American cities, exclusive of industrial wastes. It is recognized, however, that the element of personal judgment enters into any such summary, as the results depend largely upon the choice of data. The values in this table are, therefore, presented chiefly as a record of the basis of calculations employed in this report, not with any claim that they are more precise than the somewhat different values given by various authorities.

TABLE No. 45.—*Average ratios of various constituents to sewered population—Grams per capita per diem in domestic combined sewage, exclusive of major trades wastes*

Grams per capita per diem							
Solids				Nitrogen		Oxygen consumed	Biological oxygen demand
Total	Suspended	Dissolved	Volatile	As free NH_3	Total		
439	109	330	182	7.6	11.4	51.5	100

In so far as these ratios—or any others which may be adopted in preference to them—may be considered as fair average values, they constitute a link between the observations made in a survey of sources of pollution and the observations made by direct examination of water as found in the river. They make it possible to convert data collected in terms of sewered population into terms of physical and chemical analysis, and thus to compare the amounts of various constituents actually found in the river with the amounts accounted for in the domestic sewage of all urban communities on the watershed above.

As regards bacterial pollution, no attempt has been made to derive any similar factors for the conversion of sewered population into terms of standard bacteriological determinations except as indicated by observations subsequently made in the course of this study. (See Section VI, pp. 243–256.)

INDUSTRIAL SEWAGE

The survey of communities on the watershed undertaken to collect data regarding the sources of sewage pollution included a fairly comprehensive and detailed survey of industrial wastes. In each community which was included in the itinerary of the survey parties all the major waste-producing industrial plants were visited by the engineer member of the field party, who collected all information available regarding the composition and amount of the wastes discharged. Naturally, it was hardly ever possible to obtain any direct records of analyses or volumetric measurements of the wastes from individual industrial plants, except in the rare instances where special studies had been made by the operators or by the local sanitary authorities in connection with sewage-disposal projects.

The schedule of information, therefore, ordinarily included a record of the nature of the processes employed, the kinds and amounts of raw materials used, the number of employees, the kinds and amounts of finished product, the sources and quantities of water used, and such general information as could be elicited regarding the character of the wastes discharged directly or indirectly into the river system. Even this information was seldom available in full, notwithstanding a very general willingness on the part of the operators to furnish whatever information they possessed.

The data thus collected were supplemented by records made available by State industrial commissions and by correspondence with the operators of industrial establishments located in communities which were not visited. In this way more or less complete records were obtained from 1,433 industrial establishments, including, it is believed, a great majority of the larger waste-producing plants on the watershed.

These wastes may be grouped primarily into two classes, namely:

(1) Wastes containing large amounts of more or less unstable and putrescible organic matter.

(2) Wastes of radically different and diverse character, as, for example, the acid wastes from coal mines and certain steel industries, oil wastes, and wastes from various chemical industries.

Obviously there are no common and significant terms in which these two classes of wastes can be combined; but to a limited extent the wastes of the first class may be summarized in terms of certain constituents or indices of organic matter.

Ratios of certain industrial waste constituents to raw materials, products, and employees.—For the purpose of such a summary the organic wastes have been classified, first, according to character of manufacturing processes used, into the groups shown in Table No. 46. Data were then collected from all available sources relative to volumetric measurements and chemical analyses of the wastes from plants representing each class of industrial processes, together with records of raw materials used, finished product, and number of employees, in an attempt to ascertain the average ratio of waste constituents to some determinable unit of raw material or product. Wherever possible these data have been supplemented at the stream pollution laboratory, in Cincinnati, by special studies of wastes from industrial plants in that vicinity.

The end results of this attempt to summarize organic industrial wastes in common terms are given in Table No. 46, which shows, for each of the more important waste-producing industries represented on the Ohio watershed, the estimated weights of total nitrogen and of "oxygen consumed" discharged in their wastes per unit of product, of raw material, or of labor.[11]

TABLE NO. 46.—*Estimated average amounts of total nitrogen and oxygen consumed contained in various industrial wastes, per unit of product, raw material, or labor*

Nature of waste	Unit	Content of wastes in kilograms per unit	
		Total nitrogen	Oxygen consumed
Brewery	1 barrel (product)	0.0230	0.7053
Distillery	do	.9752	22.0722
Animal products:			
Slaughter house	1 animal (raw material)	.2386	.1837
Pork packing	do	.2431	.3075
General packing	do	.1715	.3442
Rendering	1 employee	.4082	1.5649
Glue making	do	3.1933	4.4271
Grease and oil refining	do	.0181	.4717
Soap	do	.0272	20.8474

[11] In some instances the available data on wastes have been more directly related to amount of product, in other instances to amount of raw material, and in still other instances to number of employees, hence the different bases used in this table.

TABLE No. 46.—*Estimated average amounts of total nitrogen and oxygen consumed contained in various industrial wastes, per unit of product, raw material, or labor*—Continued

Nature of waste	Unit	Content of wastes in kilograms per unit	
		Total nitrogen	Oxygen consumed
Textiles:			
Wool, scouring	100 pounds (raw material)	0.3402	1.5513
Wool yarn and cloth—			
Scouring	do	.4005	1.2701
Dyeing	do	.1628	.7620
Dye and scour	do	.7044	7.1124
Cotton yard and cloth—			
Bleaching	do	.3561	6.3504
Dyeing	do	.0481	1.3100
Bleach and dye	do	1.1113	6.1599
Cotton bleaching, dyeing, and finishing	do	.1334	.7666
Paper:			
Sulphite pulp liquor	1 ton pulp (product)	1.3154	647.741
General paper mill	1 ton paper (product)	19.5048	29.9376
Leatherboard	1 ton (product)	21.7742	43.9992
Strawboard	do	5.7154	151.5024
Straw and paper board	do	2.8577	73.0296
Tanning:			
Hide tannery	1 skin (raw material)	.1633	1.2610
Calfskin tannery	do	.0454	.3538
Sheepskin tannery	1 dozen skins	.0272	.1315

It will be readily understood that the figures given in this table are not in any sense exact. In the first place, the data upon which they are based are, with some exceptions, quite fragmentary, and in many instances indirect. Also, even if much more extensive data were available no very exact or constant ratios could be established, since the relations of waste to product, raw materials, or employees may be quite variable in different plants of the same general class. Therefore, the values given are to be considered only as approximations, applicable at best to the combined industries of a large area, but not to individual plants. It may be said, however, that they have been compiled with care—more, perhaps, than the material warrants—and that they are at least reasonably representative.[12]

It should, of course, be noted as regards these values that equivalent amounts of nitrogen or of "oxygen consumed" in different wastes do not necessarily indicate equivalence with respect to offensiveness, which depends in considerable degree upon characteristics not very highly correlated with these indices of organic matter. A more significant basis of comparison would be the biological oxygen demand, since this is more closely correlated with offensiveness, but unfortunately the available data on oxygen demand of industrial wastes are as yet too fragmentary for any such summary.

In view of the varied character of the wastes which are represented in Table No. 46, and the incompleteness of the data available

[12] The detailed data used in arriving at these estimates will be presented in a later publication dealin specifically with the composition of organic industrial wastes.

for arriving at the values there given, it may well be questioned whether the attempt to reduce such heterogeneous material to a common denominator is justified. It is believed, however, that in this instance it is justified as the only procedure which permits any quantitative comparison, however imperfect, between industrial wastes and other sources of pollution in such a broad area as the Ohio watershed.

Summary of organic industrial wastes in terms of certain constituents.—Applying the conversion factors given in Table No. 46 to the data collected in the field survey of industrial wastes on the watershed, the results are as indicated in Table No. 47, which shows the estimated weights of nitrogen and of "oxygen consumed" discharged into the river system daily in the wastes from industries of each designated class.

TABLE No. 47.—*Estimated amounts of organic matter, in industrial wastes of designated classes, discharged daily*[1] *into the Ohio River system, expressed in terms of total nitrogen and oxygen consumed*

[Estimates refer to the years 1914 and 1915]

Classes of wastes	Kilograms per diem in terms of—					
	Total nitrogen discharged into—			Oxygen consumed discharged into—		
	Entire river system	Ohio River direct	Tributary streams	Entire river system	Ohio River direct	Tributary streams
Brewery	744	435	309	22,864	13,351	9,513
Distillery	3,901	981	2,920	88,374	22,231	66,143
Meat packing	4,082	2,155	1,927	7,541	3,837	3,704
Rendering soap and glue	5,552	632	4,920	61,637	49,802	11,835
Textiles	1,051	120	931	11,191	1,172	10,019
Paper	39,887	4,889	34,998	258,617	17,323	241,291
Tannery	3,055	651	2,404	23,593	5,030	18,563
Total	58,272	9,863	48,409	473,817	112,746	361,071

[1] The amounts given are *average* daily amounts, based upon annual production distributed uniformly over the year. Actually the discharge is not thus uniformly distributed, since many plants operate during only a part of the year; and, when in operation, do not necessarily discharge the same amounts of wastes each day.

It will be observed in the above table that the waste-producing industries are not concentrated directly upon the Ohio River to the same extent as is the urban population. While the urban population situated directly upon the river constitutes 36 per cent of the total on the watershed, the industrial wastes discharged directly into the main stream, expressed in terms of total nitrogen, constitute only 17 per cent, and in terms of oxygen consumed only 24 per cent of the total for the watershed.

The distribution of these wastes, of all classes, upon tributary drainage areas is shown in Table No. 48, from which it is seen that the watersheds of the Allegheny, Monongahela, Muskingum, Scioto, Miami, and Wabash Rivers are the largest contributors.

TABLE No. 48.—*Estimated amounts of organic matter in industrial wastes discharged into various sections of the Ohio River system*

Stream	Kilograms per day of organic matter as—	
	Total nitrogen	Oxygen consumed
Allegheny	24,083	144,671
Monongahela	1,101	22,116
Chartiers Creek	54	308
Beaver	244	2,460
Muskingum	1,210	28,701
Hocking	15	202
Scioto	1,551	13,647
Little Miami	163	4,286
Licking	40	916
Miami	12,271	37,530
Kentucky	215	4,876
Salt	404	9,164
Green	0	0
Wabash	6,167	83,634
Cumberland	110	899
Tennessee	775	7,657
Ohio River direct	9,861	112,742
Total for watershed	58,264	473,809
For metropolitan district of:		
Pittsburgh	5,529	11,755
Wheeling	365	1,503
Cincinnati	2,827	66,905
Louisville	980	14,938

Comparison of industrial wastes with domestic sewage.—For a comparison of industrial wastes with domestic sewage, the values given in Table No. 45, representing the average weights of nitrogen and of "oxygen consumed" discharged in domestic sewage per capita of sewered population per diem, have been applied to the estimated daily discharge of these constituents in industrial wastes, as shown in Table No. 48. Calculations have thus been made of the sewered populations which would discharge, as domestic sewage, the amounts of nitrogen and "oxygen consumed" actually attributed to industrial wastes, with results as shown in Table No. 49.

TABLE No. 49.—*Comparison of actual sewered population on principal tributary basins of the Ohio River, with estimated equivalents of sewered population represented by organic industrial wastes, as calculated from relative amounts of* (a) *total nitrogen and* (b) *oxygen consumed*

Watershed	Actual sewered population	Sewered populations equivalent to industrial wastes in terms of—	
		Total nitrogen	Oxygen consumed
Allegheny	347,000	2,112,500	2,809,100
Monongahela	370,100	96,600	429,400
Chartiers Creek	38,800	4,700	6,000
Beaver	220,000	21,400	47,800
Muskingum	173,500	106,100	557,300
Little Kanawha	none	none	none
Hocking	18,000	1,300	3,900
Kanawha	52,900	none	none
Guyandotte	none	none	none
Big Sandy	6,900	none	none
Scioto	248,200	136,000	265,000

TABLE No. 49.—*Comparison of actual sewered population on principal tributary basins of the Ohio River, with estimated equivalents of sewered population represented by organic industrial wastes, as calculated from relative amounts of (a) total nitrogen and (b) oxygen consumed*—Continued

Watershed	Actual sewered population	Sewered populations equivalent to industrial wastes in terms of—	
		Total nitrogen	Oxygen consumed
Little Miami	6, 200	14, 300	83, 200
Licking	9, 500	3, 500	17, 800
Miami	180, 400	1, 076, 400	728, 700
Kentucky	24, 500	18, 900	94, 700
Salt	4, 300	35, 400	177, 900
Green	2, 300	none	none
Wabash	501, 200	541, 000	1, 623, 900
Saline	1, 200	none	none
Cumberland	87, 200	9, 600	17, 500
Tennessee	172, 700	68, 000	148, 700
Ohio River direct, and minor streams	1, 641, 700	864, 900	2, 189, 100
Total for watershed	4, 106, 600	5, 108, 600	9, 200, 000
For Metropolitan district of:			
Pittsburgh	827, 300	485, 000	228, 400
Wheeling	59, 500	32, 000	29, 100
Cincinnati	494, 300	248, 000	1, 299, 200
Louisville	179, 800	86, 000	290, 100

From this table it appears that the organic industrial wastes discharged into the Ohio River system from the major waste-producing industrial plants are equivalent, in terms of total nitrogen, to a sewered population of 5,100,000, and in terms of oxygen consumed to a sewered population of 9,200,000. The actual sewered population on the watershed being approximately 4,106,600, the industrial-wastes equivalent is 124 per cent of this total in terms of nitrogen, and 230 per cent in terms of oxygen consumed. The validity of these figures depends upon the precision of the data used in the somewhat complicated processes followed in arriving at them; and it is obvious that the margin of error, though indeterminate, is quite wide. It is considered, however, that the figures given as to amounts of industrial wastes are conservative; that is, that they understate rather than overstate the actual total, since the principle of conservatism has been followed in arriving at conversion factors, and since, moreover, the summation does not include the wastes from all small plants of the classes considered. Also certain industries, such as canneries and creameries, are entirely omitted, due to lack of adequate data.

Even if the estimates are approximately correct in terms of nitrogen and oxygen consumed, it does not follow that industrial wastes and domestic sewage have the relative importance which these figures indicate, with respect to objectionable organic pollution of the river. It has already been stated, but may be repeated, that the significance of determinations of total nitrogen and of oxygen consumed is quite variable, bearing no general and constant relation to offensiveness

of the organic matter which they attempt to measure. The figures are, however, not without significance in the interpretation of analyses of the river water expressed in these same terms, and it is only for this limited purpose that they are used.

As regards the importance of industrial wastes in relation to bacterial pollution, it would seem quite impossible, at this time, to make any quantitative estimate at all. Even extensive bacteriological examinations of the wastes as discharged from industrial plants would afford no direct and reliable evidence, for certain of the wastes which are potentially of high bacterial content may actually have a very low content as discharged from the plants. Such wastes may quite possibly influence the bacterial content of mixed sewage by promoting the multiplication of bacteria already present rather than by adding immediately and directly to their numbers.

POLLUTION FROM UNSEWERED AREAS

As regards the unsewered areas which contribute to the pollution of the river system by their natural drainage, it is obvious that the aggregate of wastes from these sources must be very great, but any attempt to make a direct quantitative estimate based upon summation of areas would be futile. Certain of the constituents included in quantitative analyses of the river water are evidently derived almost wholly from natural surface drainage, as, for example, the suspended matter, which consists chiefly of soil particles, and many of the inorganic compounds in solution. It is possible, also, by indirect methods, to show that a large proportion of the organic matter found in the Ohio River must necessarily be derived from the surface drainage of unsewered areas, presumably rural areas, and that this proportion varies according to rainfall and run-off; but as these inferences depend upon the results of direct examinations of the river waters, they are discussed in connection with the results of chemical analyses, in Section V.

SECTION IV

GENERAL PLAN AND METHODS OF LABORATORY STUDIES

By W. H. FROST

The laboratory studies which constitute the central feature of this report were carried out during the year 1914 in a series of temporary laboratories, established for this purpose at intervals along the Ohio River, and were continued throughout the years 1915 and 1916 at two of these laboratories, at Cincinnati and Louisville. The observations at these laboratories consisted of chemical, bacteriological, and biological (plankton) examinations of samples of water collected at frequent intervals throughout the period of study from fixed sampling stations on the Ohio and certain of its principal tributaries. The examinations made were quite simple in character, consisting chiefly of the quantitative determinations ordinarily made in the examination of water supplies, and more or less closely following the standardized technique recommended by the American Public Health Association. Such special significance as the results may have depends not upon anything unusual in the character of the observations but rather upon their mass and their quantitative relations to each other and to coincident observations upon sources of pollution, volume of discharge, and times of flow from point to point. It seems desirable, therefore, before presenting the results of chemical and bacteriological examinations, to outline the purposes which they were intended to serve, to explain the considerations which governed the selection of sampling stations and schedules of collection, and to give such general description of bacteriological and chemical technique as is necessary for interpretation of results. Details of technical precedure which are not required for comprehension of analytical results, but which are necessary for comparison with data from other studies, either past or future, are given in the appendix.

The purpose of the laboratory studies, briefly stated, was to ascertain in quantitative terms the actual intensity of pollution existing in the Ohio River in different zones and under varying conditions of streamflow and season, for correlation, on the one hand with the causes contributing more or less directly to the pollution and on the other hand with its consequences in relation to the public interest.

EFFECTS OF POLLUTION

The most definite and serious public injury resulting from the pollution of the river is the actual or potential contamination of its waters with pathogenic bacteria in zones from which water supplies are taken. The largest, and to that extent the most important, of the water supplies taken from the Ohio River are drawn from the zones immediately above the larger cities, and in relation to this danger it is of obvious importance to ascertain the conditions of pollution, especially bacterial pollution, existing in these zones.

The ill effects of sewage pollution, other than the dangerous contamination of water supplies, are nuisances resulting from such excessive fouling as may render the waters offensive to sight or smell or unfit for legitimate industrial or recreational uses. These conditions are likely to be most offensive, or to most nearly approach offensiveness, in the zones immediately below large centers of population, discharging domestic and industrial sewage into the river, and from this point of view special importance attaches to ascertaining the character and intensity of pollution in these zones.

In the upper Ohio a special case exists of pollution not known to be injurious to health but of quite serious economic importance, namely, contamination with acid wastes originating in the drainage from coal mines, and the pickling liquors and other wastes discharged from certain of the industrial plants. This is a matter of sufficient importance in relation to the whole biology of the river to warrant special and intensive study; but while the condition was known to exist when this survey was begun its full import was not and perhaps could not be recognized until after the plans for study had been matured, and it was not given so much attention as it undoubtedly deserves.

FACTORS WHICH DETERMINE THE STATUS OF POLLUTION

As regards the relation between existent conditions of pollution and their causes, special significance attaches to measurable changes in pollution due to the influence of individually determinable factors. The status of pollution is determined by the balance of three factors: The volume of water, the amount and character of polluting waste, and the kind and extent of the changes which have taken place in the mixture, due to the action of many and complex physical and biological agencies. Any change in the established status must, therefore, be due to the influence of one or more of these factors. This is true equally of the variations noted from time to time in conditions at any given cross section, and of the simultaneous differences between any two sections.

Varying conditions at the same cross section are usually attributable to coincident variations in two or more factors. For instance, an

increase in volume of the river is accompanied by an increase in velocity, affecting the time of passage between given points, and usually by an increase in the amount of surface drainage entering the watercourse above. Such changes as may take place from time to time in the chemical or biological condition of the water at the same cross section are, therefore, not a measure of the influence of any single factor.

Better opportunities for determining the effects of single factors are afforded by comparison of simultaneous conditions at two sections, between which only one important variable has been introduced, such as:

(1) The abrupt increase of pollution within a distance of a few miles due to the discharge of sewage from a large, compact urban district.

(2) The inflow of an important tributary, which may either increase or decrease the concentration of the pollution, according as the waters of the tributary are more or less highly polluted than those of the main stream. For a full analysis of the elements of change in this case it is necessary to know the discharge as well as the degree of pollution of the main stream above and below the tributary junction, also the discharge and degree of pollution of the tributary.

(3) The action of natural physical and biological forces, in a stretch within which the river receives no significant increment of pollution or dilution. The combined and complex natural forces operative in such a stretch can not properly be termed a "single factor" except that, taken together, they constitute the only factor other than additional polluting matter or dilution capable of changing the established status.

The change due to any one of these causes is measurable only when it can be shown that the influence of other factors between the sections compared is negligible, and when the extent of the change in conditions considerably exceeds the range of probable error in the observations. For instance, assuming that the "probable error" in the bacterial count at a sampling station is 20 per cent, an increase or decrease within this limit is not accurately measurable and therefore is not definitely significant, whereas, in a change of several hundred per cent, this error (of ± 20 per cent) becomes relatively unimportant and the change correspondingly significant.

GENERAL CONSIDERATIONS GOVERNING THE LOCATION OF LABORATORIES

In order to serve the purposes indicated, sampling stations for a comprehensive study of a river should obviously be located at the following points on the stream:

1. For the study of conditions of pollution with special reference to their effects:

(*a*) Immediately above large cities, where large water supplies must be taken.

(*b*) Immediately below large cities, where conditions of pollution are most acute.

2. For the study of conditions of pollution with reference to the influence of individually determinable factors:

(*a*) Immediately above and immediately below large cities, to observe the increase in pollution from these sources.

(*b*) On large tributaries, at or near their mouths.

(*c*) Immediately above and below large tributaries to observe the effect of their inflow.

(*d*) At the upper and lower ends, respectively, of stretches within which the river receives no important additions to its volume or its sewage pollution. These stretches, to show measurably the influence of natural agencies, must be of considerable length, ordinarily not less than 5 to 10 miles, and preferably much longer.

(*e*) Where the stretches are of sufficient length, it is desirable that additional sampling stations should be located at suitable intervals between the upper and lower limits, in order to afford a wider range of observations upon the rates at which changes take place.

Since bacteriological samples must be examined within a few hours after their collection, sampling stations must be accessible to laboratories, usually not more than 15 to 30 miles distant. For the study of the changes taking place in a long stretch of river, say 50 to 100 miles in length, it is necessary that a laboratory be located near each end of a stretch, otherwise the difficulties and expense of sufficiently rapid transportation of samples are prohibitive. If the number of laboratories be limited, they must be so located as to cover the maximum number of important zones on the river.

Location of laboratories on the Ohio River.—Considering the Ohio River from the standpoint of suitable locations for laboratories and sampling stations in this plan of study (see fig. 14, and Table No. 40, p. 69), there are immediately upon its banks five large compact population groups dependent upon the river for their water supplies and discharging sewage directly into the stream, namely:

(1) The Pittsburgh metropolitan district, situated at the head of the river; population (1915), about 1,153,000.

(2) Wheeling, W. Va., and immediately adjacent territory, situated about 90 miles below Pittsburgh; population, about 88,300.

(3) The Cincinnati metropolitan district situated 465 miles below Pittsburgh; population, about 594,700.

(4) The Louisville metropolitan district, 600 miles below Pittsburgh; population, about 306,200.

(5) Evansville, Ind., 780 miles below Pittsburgh, population 72,100.

The other cities and groups of cities along the river are all relatively small, none having more than 50,000, and few having more than 20,000 inhabitants.

The 18 major tributaries which the Ohio receives join the main stream at irregular intervals; and in only a few instances are the tributary junctions sufficiently near large cities to be accessible from laboratories located in the latter.

Stretches of river receiving no considerable urban sewage pollution and no important tributary, and of sufficient length for a significant study of the phenomena of natural purification are found at intervals between the large cities and tributary junctions along the whole course of the river. However, such stretches offer favorable opportunities for study only when they are of considerable length, and when they lie between two points which are in other respects suitable locations for laboratories.

After a preliminary survey of the river had been made with these considerations in view, it was concluded that six laboratories would be the minimum number required, and that these could be most advantageously located at Pittsburgh, Wheeling,[1] Portsmouth, Cincinnati, Louisville, and Paducah. The sampling stations accessible from these six cities would serve to show:

(1) Conditions at the origin of the Ohio, that is at Pittsburgh, and near its mouth (Paducah), below the junction of all important tributaries.

(2) Conditions above and below four of the five largest population groups on the river, and the polluting effect of the wastes discharged from each of the groups, namely, the Pittsburgh, Wheeling, Cincinnati, and Louisville districts.

(3) The condition and effect upon the main stream of 7 of the 18 major tributaries joining the Ohio below the confluence of the Allegheny and Monongahela, namely: The Beaver, Scioto, Little Miami, Licking, Miami, Cumberland, and Tennessee Rivers.

(4) The effect of natural agencies operating (*a*) in relatively short stretches immediately below each of the four large cities, and (*b*) in two long stretches, namely, between the Portsmouth and Cincinnati districts, and between the Cincinnati and Louisville districts. Both of these stretches are almost entirely free from increments of sewage pollution, and the inflow which they receive from tributaries is not sufficient to make any material change in the status of pollution.

This distribution of laboratories leaves two long reaches of the river within which no observations were made, namely, from Wheel-

[1] Although the population of Wheeling is less than that of Evansville, the sewered population of Wheeling and its immediate environs exceeds that of Evansville. Hence the Wheeling district is fourth with respect to sewage discharged into the Ohio.

ing to Portsmouth, Ohio, and from Louisville to the mouth of the Cumberland River. Within the first of these stretches, from Wheeling to Portsmouth, a distance of about 245 miles, the river receives six large tributaries and direct sewage pollution from a series of cities and villages with an aggregate of 144,000 inhabitants, the largest of these cities being Huntington, W. Va., with a population (1915) of about 47,000. While the combined effect of these several tributaries and cities is undoubtedly of some importance, it is probable that no single city or tributary by itself makes a distinctly measurable change in the pollution of the river.

Practically the same may be said of the long stretch of river from Louisville to Paducah, nearly 300 miles. Evansville, Ind., the only city of sufficient size to have a considerable effect upon the pollution of the Ohio, was not considered an effective location for a laboratory because the sewage pollution from Owensboro, Ky., some 30 miles upstream, obscures the effect of natural purification in the stretch between the Salt and the Green Rivers, while the pollution from Henderson, Ky., 12 miles below Evansville, interrupts any study of progressive purification below Evansville.

These two long stretches of the Ohio have, therefore, been passed over. The total change in conditions of pollution between their upper and lower limits was determined, but with no attempt to analyze the influence of individual cities and tributaries or to measure precisely the influence of natural agencies of purification.

GENERAL PLAN AND DEVELOPMENT OF LABORATORY WORK

The work carried on at these six laboratories was quite simple in its general plan. Each of them was equipped for the usual bacteriological examinations of water and for such simple procedures of chemical analysis as determinations of turbidity, alkalinity, and dissolved oxygen, and was placed in charge of a technically trained scientific assistant, with two or more helpers. Examinations which require more elaborate equipment or more specialized training, such as mineral and sanitary chemical analyses and microscopic examinations of plankton, and which need not be made within a few hours after the collection of samples, were made only at the central laboratory, at Cincinnati, the samples collected at other stations being shipped to Cincinnati for these special examinations.

By the use of motor boats and by other arrangements, it was possible to extend the radius of sampling some 10 to 20 miles in each direction from each laboratory and still to have samples delivered at the laboratories within two to four hours after collection; and in all the laboratories daily examinations were made of samples collected at regular and frequent intervals from fixed sampling points over a period which varied, at different laboratories, from eight months to three years.

This plan of work, though quite simple in its general outline, presented many difficulties in matters of detail, such as the precise location of sampling stations, the careful standardization of minor details of laboratory technique, and the distribution of work so that it could be handled by the available personnel. As these and many other essential details could be satisfactorily adjusted only on the basis of actual experience, it was necessary, in order to avoid wasted effort, to begin the laboratory work on a small scale, extending it to full scope only after sufficient preliminary work had been done to insure against the necessity of material alterations in procedure.

A central laboratory was, therefore, first established, in July, 1913, at Cincinnati, Ohio, this city being selected for headquarters because of its central location, about midway between the origin and the mouth of the Ohio River. The laboratory established there was equipped for chemical (both sanitary and mineral) analyses of water and for microscopic (plankton) studies, in addition to its equipment for the bacteriological and simpler chemical tests included in the routine examination of samples.

Upon completion of the necessary preliminary field work, the collection and examination of samples from near-by points on the Ohio River was begun at Cincinnati in the early part of November, 1913. In the meantime, subsidiary laboratories had been established at Pittsburgh and Portsmouth, and at both these stations the collection and examination of samples were begun about December 1. The work of these three laboratories was at first preliminary, designed to test the plans and methods provisionally laid out, and to develop a satisfactory system. As was to be expected, some changes were found to be necessary in the details of procedure in collection and examination of samples, and not until January 1, 1914, were the details of the work at these three laboratories sufficiently developed to warrant adoption of a uniform and permanent schedule.

At this time, January 1, 1914, a fourth laboratory was opened at Louisville, Ky. During the next two months the work at these four laboratories, though fairly uniform and satisfactory, was much interrupted, due to ice in the river and to other circumstances interfering with boat service. Also, during this period, a number of minor changes in methods were found to be necessary, especially in the location of sampling stations and in the manner of collecting samples, so that it was not considered advisable to establish additional laboratories and further extend the studies until late spring.

During April, 1914, two additional laboratories were established, one at Wheeling, W. Va., and one at Paducah, Ky.; and at both these laboratories systematic work was begun May 1. By this time all necessary readjustments in the plan and methods of work had been made, so that from this date forward work proceeded on a satis-

factorily coordinated plan without material change throughout the remainder of the period of study.

On account of the expense involved in maintaining six laboratories, it was necessary to reduce the scope of the work before the close of the year 1914. Accordingly, the work at the Pittsburgh, Wheeling, Portsmouth, and Paducah laboratories was discontinued October 15, 1914. The work at Cincinnati and Louisville was, however, continued through the entire year 1914, and was subsequently extended through the years 1915 and 1916, as it had become apparent, after the first few months of study, that the river between these two cities afforded exceptionally favorable opportunities for the quantitative study of natural purification.

The laboratory studies may, therefore, be divided into four periods according to the extent and uniformity of the observations made, namely:

(1) November and December, 1913, were devoted to preliminary orienting work at Cincinnati, Pittsburgh, and Portsmouth. The methods during this period not being uniform, the results are omitted from the data presented and discussed in this report.

(2) From January 1 to May 1, 1914, four laboratories were in operation upon a regular schedule; and though various minor changes were made during this period, the results are on the whole comparable to those obtained in the next period. They apply, however, to a smaller number of sampling stations and do not include certain determinations subsequently added to the schedule.

(3) From May 1 to October 15, 1914, the period of maximum development of the work, a regular schedule of observations was followed without change or interruption at six laboratories, distributed along the whole length of the river.

(4) From October 15, 1914, observations were limited to the river and its tributaries in the vicinity of Cincinnati, and from that city to Louisville. The bacteriological and some of the chemical examinations of samples from this portion of the river were continued through the years 1915 and 1916, thus establishing a continuous and uniform record of observations for three full years.

It would obviously have been preferable to have continued observations at all six laboratories throughout a full cycle of seasonal changes, but, as this was not possible, it may be considered fortunate that the period of most extensive studies, from May 1 to October 15, 1914, covered an unusually wide range of stream flow conditions, ranging from moderately high river stages during May to exceptionally low stages during the first half of October. With the added observations at Pittsburgh and Portsmouth during January, February, March, and April, 1914, and the three years of observation at Cincinnati and Louisville, the changes in pollution of the river which are associated with the characteristic seasonal variations in temperature and discharge are fairly well defined.

LOCATION OF SAMPLING STATIONS

Each sampling station on the Ohio River, as referred to in this report, is designated by a number which corresponds to its distance, in miles, from Pittsburgh, measured from the confluence of the Allegheny and Monongahela Rivers along the low-water line on the left bank, as shown in the maps of the United States Army Engineer Corps. Sampling stations on tributary streams are designated by the names of the tributaries, and, in the case of the Allegheny and Monongahela Rivers, by numbers indicating the distance in miles from the mouth of the tributary. Thus, station Allegheny-7, indicates a sampling station located on the Allegheny River 7 miles above its confluence with the Monongahela.

The purpose which any sampling station was intended to serve would, of course, fix its approximate location, as above or below a city or tributary; but this would define the location only in a rather general way, within limits of perhaps several miles. The precise locations of sections for sampling were governed by several additional considerations, of which the more important are the following:

1. Sampling stations located below the inflow of sewage or of a tributary must be sufficiently far downstream to allow of fair lateral mixture of the flow, yet not so distant that the effect of the inflow would be obscured by subsequent biological changes. Ordinarily such stations were located not less than 1 nor more than 3 miles below the nearest important sewer outlets or tributary junctions.

2. So far as practicable advantage was taken of chutes, dikes, dams, and narrowing of the channel, tending to give a good lateral mixture.

3. To insure good vertical mixture, sections were located preferably in or beyond shallow portions of the channel, or below dams, rather than in pools.

4. Stations below dams were placed not nearer than one-half mile below in order to allow for the escape of air which might have been entrained in the fall over the dam.

5. The sampling stations were located by preference on cross sections of uniform contour, in straight stretches, where the flow would be at right angles to the section.

6. Sampling stations on tributaries, except the Allegheny and Monongahela, were located as near as practicable to their mouths, but sufficiently upstream to avoid actual back flow from the main stream, though it was not practicable to go beyond the influence of slack water at high stages of the Ohio. Where tributaries at their junctions were polluted with sewage from towns situated at their mouths, sampling points were placed above the major sources of such pollution.

The number and location of the points on a cross section from which samples should be taken in order to give a sufficiently representative average for the section will obviously vary according to the uniformity of mixture across the section. At certain sampling stations, such as station No. 461, above Cincinnati, or station No. 598, above Louisville, a single sample from any point in the channel would probably answer the requirements, as the pollution at these sections is chiefly from distant sources, and the mixture is quite uniform. At other sections, especially below large cities, the mixture of sewage with the river water is by no means uniform, and varies from day to day according to river stage, so that an exact average for the section might require the careful integration of samples collected from a large number of points. It was decided, however, after careful consideration and some preliminary studies, to follow the uniform practice of taking samples from three points on each section.

The most precise method for locating the three sampling points best representing the flow at any section would be to divide the cross-sectional area of flow corresponding to each river stage into three vertical areas, through each of which an equal volume of water was passing, then to select as sampling points the center of mass in each area. But while the location of these points on a plot of the cross section would present no great difficulties, the necessity of changing the location of sampling points from day to day, with each change in river stage, would very greatly complicate the work of sample collection. Moreover, as the changes in location would often not exceed a boat length, it is apparent that no such precision of sampling could be carried out in actual practice.

As a practical approximation, sufficently accurate for the purpose, the cross section below an "average" elevation of the water surface was divided vertically into three equal areas, each of which was in turn equally divided by a vertical line, as indicated in Figures 18 and 19, showing a specimen cross section. *The sampling points chosen were at mid-depth on these lines.* These points would be approximately, though not exactly, in the center of flow of equal volumes of water at the river stage taken as average. No attempt was made to shift these points for varying river stages, except to vary the depth at which samples were taken, according to the gage-height shown from day to day on the nearest reference gage.

In locating these sampling points, a section was first selected and plotted from the soundings shown on a detailed contour map of the river bed. Sampling points located on this plot, as above indicated, were then located in the field as follows: The line of the section having been established by landmarks on either side of the river, a

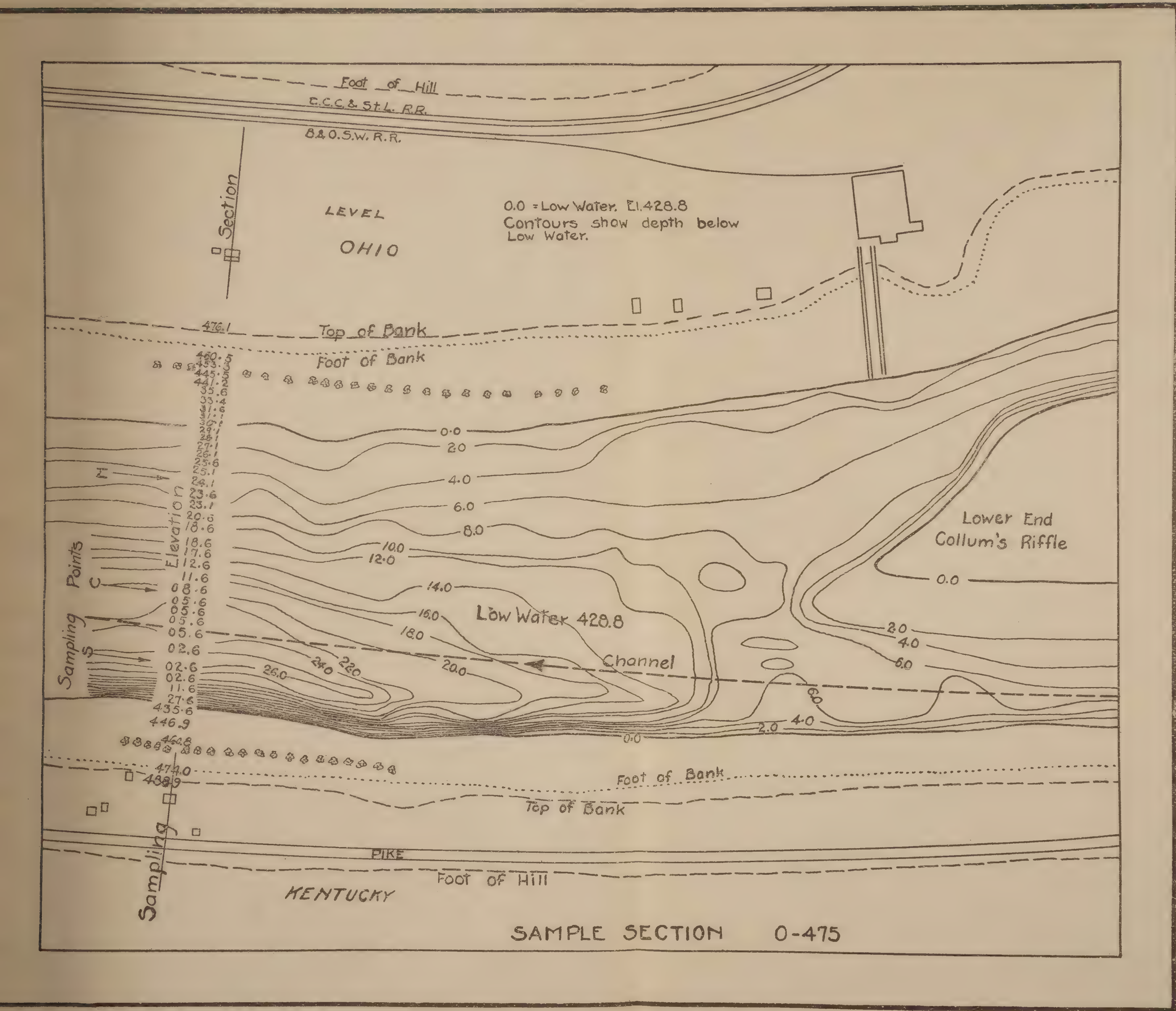

FIG. 18.—Contour map of river bed in vicinity of sampling station No. 475, Ohio River. Reproduced from map prepared by United States Army Engineer Corps

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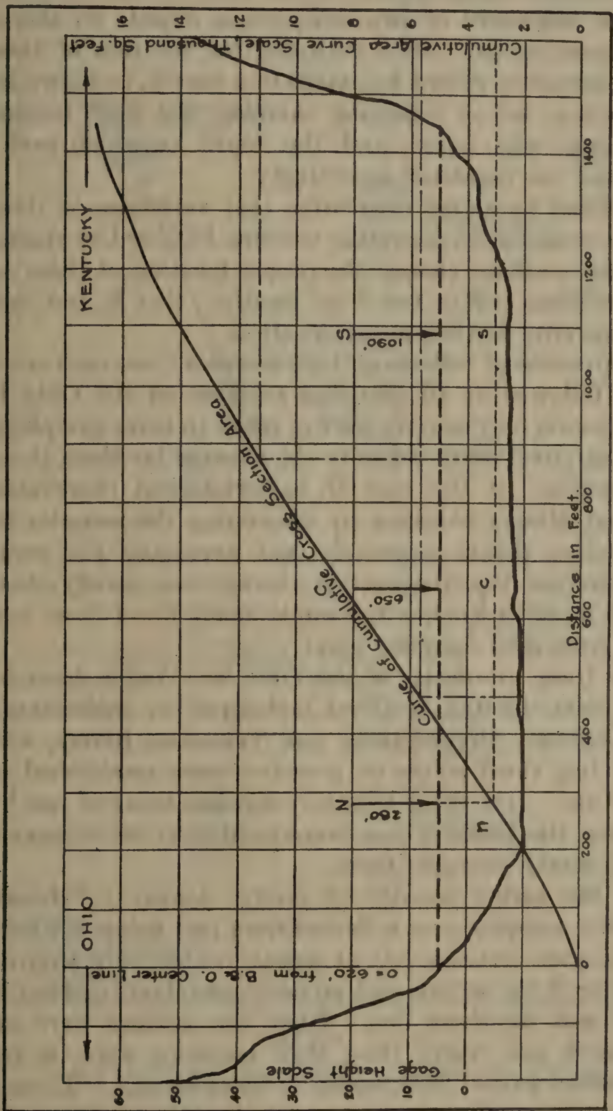

Fig. 19.
METHOD OF DETERMINING LOCATION OF SAMPLING POINTS ON CROSS SECTION
Note: Cross Section at O-482

transit was set up on this line on the river bank. A boat carryin a stadia rod set for the correct distance from the bank to the firs sampling point was then maneuvered on the section line until th stadia rod showed it to be over the sampling point. Then, on signa from the surveyor, an assistant in the boat would locate the posi tion by the alignment of two conspicuous objects on shore, estab lishing a cross range. After verifying the location of these land marks, a permanent record was made in a sketch, as shown in Figur 20. Each day, before collecting samples, the gage height at th reference gage was noted, and the depth at which each sampl was collected was regulated accordingly.

It was found by actual calculation that variations in river stage within the usual limits, excepting extreme high or low stages, woul not, at most stations, change the proper location of these samplin points more than one or two boat lengths; that is, not more tha the probable error in their actual location.

As this practice of collecting three samples from each section wa uniformly followed at all sampling stations on the Ohio River, sampling station on this river always refers to three sampling point and any analytical result refers to the average for these three point on the section. In the case of bacteriological observations thi average was always obtained by examining the samples from th three sampling points separately and averaging the results. I chemical analyses the cross-section average was usually obtained b analysis of a section-composite sample, made up of three equal por tions, one from each sampling point.

Samples from tributaries of the Ohio were taken from only on sampling point, located at about mid-depth in midstream, excep on the Allegheny, Monongahela, and Tennessee Rivers, where sta tions including three points on a section were established precisel as on the Ohio. The other tributary streams being of much smalle section than the Ohio, it was considered that midstream sample would sufficiently represent them.

During the earlier months of study, January, February, an March, 1914, samples were collected from just below the surface, o carefully located sections, but at points located only approximatel in the center of the section and on each side about midway betwee this point and the shore line. When the sections were surveyed during March and April, 1914, their locations were, in many in stances, shifted a short distance up or down stream. These change in location of sampling sections, and the change from surface t mid-depth sampling points, appear, however, not to have made an significant differences in results.

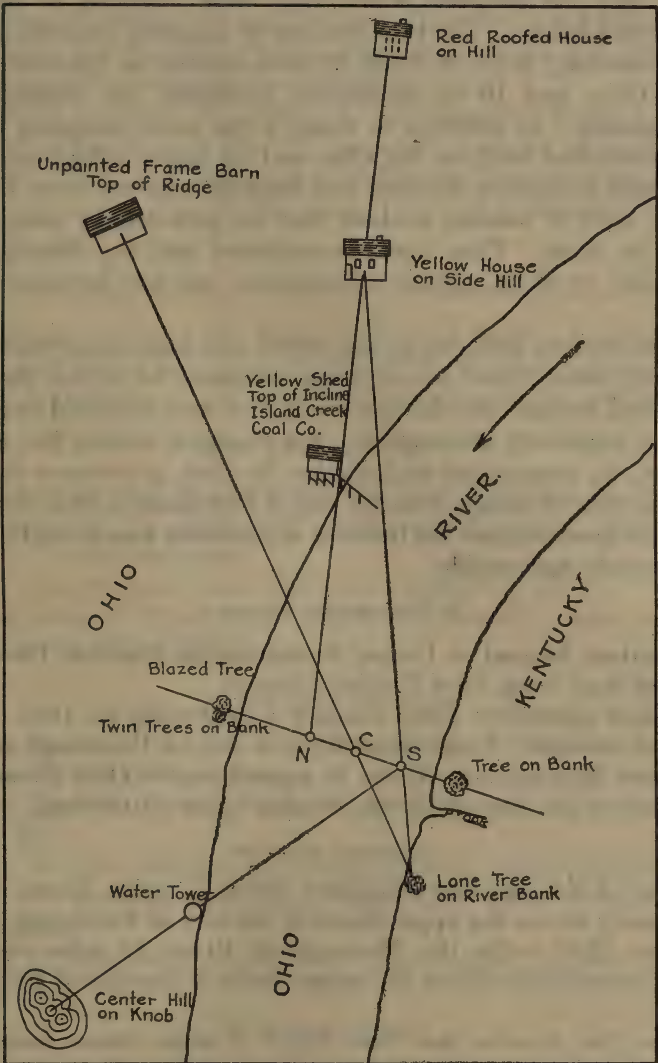

FIG. 20.

METHOD OF ORIENTING SAMPLING POINTS

Reference gage ———
Gage Reading ———Mid-depth N= feet
C= feet
S= feet

SUMMARY OF LABORATORIES AND SAMPLING STATIONS

The operations of the six laboratories, the sampling stations maintained, and the purposes which they were intended to serve are summarized below. The total number of sampling stations included in this summary is 37, of which 27 were located on the main stream of the Ohio, and 10 on tributaries, including the Allegheny and Monongahela. In addition to these, a few other sampling stations were established both on the Ohio and on minor tributaries within the several laboratory districts and samples collected from them for a while until it became evident that no well-defined purpose was served by them. They were discontinued and the records, being incomplete or of no special consequence, are not included in this report.

Of the stations included in the record and maintained throughout the study, some failed to serve the purposes for which they were established, because the changes which they were intended to measure were not accurately measurable. For example, station No. 355 was intended, by comparison with station No. 348, to measure the effect upon the river of sewage from the city of Portsmouth, Ohio, but failed of this purpose because the increase in pollution was not sufficient to be accurately measurable.

I. Pittsburgh District

Laboratory located at United States marine hospital, Pittsburgh.

Passed Asst. Surg. Paul Preble in charge.

Period of operation: From January 1 to October 15, 1914.

Stretch covered: From upper limit of city of Pittsburgh on Allegheny and Monongahela Rivers to a point on the Ohio River below the mouth of the Beaver River, 29 miles below Pittsburgh.

SAMPLING STATIONS

Station A-7.[2]—On the Allegheny River, 7 miles above mouth, immediately above the upper limits of the city of Pittsburgh proper.

Station M-12.[2]—On the Monongahela River, 12 miles above the mouth, immediately above the upper limits of the city of Pittsburgh proper.

Station No. 3.—On the Ohio River, 3 miles below junction of Allegheny and Monongahela, below sewer outlets of greater part of Pittsburgh metropolitan district.

Stations Nos. 11, 19, 23.—Between lower limits of Pittsburgh and mouth of Beaver River.

Station "Beaver."—Beaver River, one-half mile above mouth.

Station No. 29.—Ohio River, 4 miles below mouth of Beaver River.

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[2] From January to April, 1914, inclusive, samples from the Allegheny and Monongahela Rivers were taken from stations just above their confluence and subject to pollution with sewage from the city of Pittsburgh. These stations which were subsequently abandoned were designated Allegheny-1 and Monongahela-1.

IMPORTANT FACTORS

1. The sewage from a large part of the Pittsburgh metropolitan district, discharged between stations A–7 and M–12, above, and station No. 3, below, including sewage discharged into two small tributaries, Turtle Creek and Chartiers Creek, which empty into the Monongahela and the Ohio, respectively, within this zone.

2. Natural agencies of purification in successive zones between station No. 3 and station No. 29. As small amounts of sewage are discharged into each of these zones and as the Beaver River enters between stations 23 and 29, the effect of natural purification is more or less obscured.

INTERMEDIATE BETWEEN PITTSBURGH AND WHEELING DISTRICTS

This stretch of river, 36 miles in length, receive no important tributary but drains an aggregate area of 1,110 square miles, having an urban population of about 58,300, including 41,300 sewered.

II. Wheeling District

Laboratory located in post-office building, Wheeling, W. Va.

Asst. Surg. M. H. Neill, and subsequently Sanitary Bacteriologist M. V. Veldee, in charge.

Period of operation: From May 1 to October 15, 1914.

Stretch covered: From above city of Steubenville, Ohio, to point about 10 miles below Wheeling.

SAMPLING STATIONS

Station No. 65.—On Ohio River, immediately above Steubenville, Ohio, a city of 26,600 population.

Station No. 77.—On Ohio River at nearest practicable point below Steubenville.

Station No. 88.—On Ohio River immediately above Wheeling.

Station No. 97.—On Ohio River immediately below Wheeling and adjacent cities.

Station No. 104.—On Ohio River immediately below Moundsville, W. Va.

IMPORTANT FACTORS

1. Net change in conditions between lowest sampling station in Pittsburgh district, station No. 29, and upper station in Wheeling district, station No. 65. Since this stretch receives some slight additional sewage pollution, it does not afford an accurate measure of natural purification. Sewage from the cities of Steubenville, Mingo Junction, Wellsburg, and other smaller communities, with a combined population of about 39,400, and a sewered population of 24,500, enters the river between stations 65 and 77.

2. Extent of natural purification taking place in the stretch of 11 miles between stations 77 and 88, in which practically no additional pollution is introduced.

3. Sewage from the city of Wheeling and its environs, with a combined population of about 88,300 and sewered population about 70,100; entering the river between stations 88 and 97.

4. The effect of natural purification observed between stations 97 and 104, which is somewhat obscured by the effect of slight additional sewage pollution, chiefly from Moundsville, W. Va., sewered population, 5,300.

INTERMEDIATE BETWEEN WHEELING AND PORTSMOUTH DISTRICTS

This is a stretch of river approximately 245 miles in length, receiving at irregular intervals six major tributaries, namely, the Muskingum, Little Kanawha, Hocking, Kanawha, Guyandotte, and Big Sandy Rivers; and receiving sewage from the cities of Marietta, Parkersburg, Huntington, Ashland, Ironton, and several other smaller communities, no single one of which is of sufficient size to have a marked effect upon the pollution of the stream.

During the summer of 1914, samples were collected at weekly intervals from these tributaries near their mouths; but no other observations were made within this stretch.

III. Portsmouth District

Laboratory located in First National Bank building.

Passed Asst. Surg. L. R. Thompson and, subsequently, Sanitary Bacteriologist H. B. Corbitt, in charge.

Period of operation: From January 1 to October 15, 1914.

Stretch of river covered: From a point immediately above Portsmouth and its suburbs, 349 miles below Pittsburgh, to a point below the junction of the Scioto River, about 5 miles below Portsmouth, and 358 miles below Pittsburgh.

SAMPLING STATIONS

Station No. 349.—On Ohio River, above Portsmouth.

Station No. 355.—On Ohio River, immediately above junction of Scioto River at lower limits of city of Portsmouth.

Station "Scioto."—Scioto River at its mouth.

Station No. 358.—Ohio River, about 3 miles below junction of Scioto.

IMPORTANT FACTORS

1. Net change in conditions between the lowest sampling station at Wheeling, station No. 104, and the upper station in Portsmouth district, station No. 349. In this stretch numerous small cities discharge their sewage and several large tributaries join the Ohio.

2. Sewage from the city of Portsmouth, with a population of about 30,000 and sewered population about 10,200, discharged into the Ohio River between stations 349 and 355. The amount of sewage discharged from Portsmouth is not sufficient to make an accurately measurable increase in the pollution between these two sampling stations; also the lower station, No. 355, was not at a sufficient distance below Portsmouth sewer outlets to allow of thorough mixture.

3. The Scioto River, entering the Ohio River between stations 355 and 358. This stream is rather highly polluted, receiving the sewage from Columbus, Ohio, a city of about 209,000 population, some 125 miles above its mouth.[3]

INTERMEDIATE BETWEEN PORTSMOUTH AND CINCINNATI DISTRICTS

This is a stretch of river 103 miles in length, in which no tributary is received except minor streams draining a total area of 2,160 square miles. Direct sewage pollution is received only from two small towns, Maysville, Ky., population 6,700, sewered population 2,400; and Ripley, Ohio, population 1,840, sewered population 300.

IV. Cincinnati District

Laboratory and headquarters for the investigation located in United States marine hospital building, Cincinnati.

Passed Asst. Surg. W. H. Frost, in charge.

Period of operation: From January 1, 1914, to December 31, 1916.[4]

Stretch of river covered: From upper limits of city of Cincinnati, 461 miles below Pittsburgh, to a point below the junction of the Miami River, 492 miles below Pittsburgh.

SAMPLING STATIONS

Station No. 461.—On Ohio River, immediately above Cincinnati metropolitan district.

Station "Little Miami."—On Little Miami River, about one-half mile above mouth.

Station "Licking."—On Licking River, about 3 miles above mouth, above all except slight pollution from Cincinnati metropolitan district.

Station No. 475.—On Ohio River, below all sewer outlets from the Cincinnati metropolitan district, above Dam No. 37.

Station No. 482.—On Ohio River, 7 miles below station next above and one-half mile below Dam No. 37.

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[3] The sewage of Columbus is treated in a sewage disposal plant before its discharge into the river, but at the time of this study, 1914, the treatment works were overburdened, and from January 1 to April 20, 1914, operation was suspended.

[4] This station has been continued in operation since 1916 as headquarters for various studies relating to stream pollution.

Station No. 488.—On Ohio River immediately above mouth of Miami River.

Station "Miami."—On Miami River, about 450 yards above mouth.

Station No. 492.—On Ohio River, about 3 miles below junction of the Miami.

IMPORTANT FACTORS

1. Net change in conditions between lowest sampling station at Portsmouth (station 358) and upper station in Cincinnati district (station 461).
2. Sewage from the Cincinnati metropolitan district—population about 594,000; sewered population 494,000—entering the Ohio River between stations 461 and 475.
3. The Little Miami and Licking Rivers, entering the Ohio between stations 461 and 475.
4. Effect of natural purification, as shown between stations 475 and 482 and between 488 and 492, no significant sewage pollution entering the river in these zones.
5. Effect of the Miami River, entering the Ohio between stations 488 and 492.

INTERMEDIATE BETWEEN CINCINNATI AND LOUISVILLE DISTRICTS

This is a stretch of river 106 miles in length receiving no significant additional sewage pollution, but receiving one large tributary, the Kentucky, about midway between these two districts; also minor tributaries draining a total area of 1,680 square miles.

SAMPLING STATIONS FOR SEMI-WEEKLY COLLECTIONS OF SAMPLES, FORWARDED TO CINCINNATI FOR EXAMINATION

Station No. 543.—On Ohio River immediately above the Kentucky River.

Station "Kentucky."—On Kentucky River at its mouth.

IMPORTANT FACTORS

1. Effect of natural purification between stations 492 and 543.
2. Effect of Kentucky River as calculated from its discharge and its observed condition. Under ordinary circumstances the inflow of the Kentucky River adds not more than 10 per cent to the volume of the Ohio River and does not materially alter the condition of pollution in the main stream.

V. Louisville District

Laboratory located at United States marine hospital, Louisville.

Sanitary Bacteriologist J. W. McBurney, and subsequently, Sanitary Bacteriologist M. V. Veldee, in charge.

Period of operation: From January 1, 1914, to December 31, 1915. After April, 1915, samples were collected only from station No. 598.

Stretch of river covered: From a point above the Louisville metropolitan district, 598 miles below Pittsburgh, to a point about 10 miles below the metropolitan district and 619 miles below Pittsburgh.

SAMPLING STATIONS

Station No. 598.—On Ohio River, immediately above Louisville.

Station No. 611.—On Ohio River, immediately below sewer outlets of the Louisville metropolitan district.

Station No. 619.—On Ohio River, 8 miles further downstream.

IMPORTANT FACTORS

1. Effect of natural purification between stations 543 and 598.
2. Effect of natural purification between lowest station in Cincinnati district (station 492) and station 598, with allowance for inflow of Kentucky River.
3. Effect of sewage from Louisville metropolitan district, population 306,000, sewered population 180,000, entering between stations 598 and 611.
4. Effect of natural purification between stations 611 and 619.

INTERMEDIATE BETWEEN LOUISVILLE AND PADUCAH DISTRICTS

This is a stretch of river approximately 300 miles in length, within which the Ohio River receives three important tributaries, the Salt, Green, and Wabash Rivers, and sewage pollution from Owensboro, Ky., population 17,500; Evansville, Ind., population 72,000; and Henderson, Ky., population 12,000; in addition to several smaller communities.

The chief factors affecting pollution in this zone are the natural agencies of purification operating in a stretch of 300 miles; sewage pollution from the city of Evansville, Ind.; and the inflow of the Wabash River.

VI. Paducah District

Laboratory located in City National Bank Building, Paducah, Ky.

Sanitary Bacteriologist A. M. Besemer, in charge.

Period of operation: May 1 to October 15, 1914.

Stretch of river covered: From a point above the junction of the Cumberland River to a point about 12 miles below the city of Paducah.

SAMPLING STATIONS

Station No. 904.—On Ohio River, immediately above junction of Cumberland River.

Station "Cumberland."—Cumberland River immediately above mouth.

Station No. 920.—On Ohio River, above junction of Tennessee River and city of Paducah, Ky.

Station "Tennessee".—Tennessee River, immediately above mouth.

Station No. 926.—On Ohio River, immediately below city of Paducah.

Stations Nos. 933 and 938.—On Ohio River, 7 and 12 miles, respectively, below station No. 926.

IMPORTANT FACTORS

1. Net change in conditions between Louisville district and station No. 904.
2. Effect of Cumberland River entering Ohio between stations 904 and 920.
3. Effect of the Tennessee River, the largest tributary of the Ohio, which enters between stations 920 and 926.
4. The sewered population of Paducah which is not sufficient to make a measurable increase in pollution of the Ohio River at ordinary river stages.
5. Effect of natural purification between stations 926 and 933, and between 933 and 938. These stretches are too short to show consistently measurable effects.
6. Conditions at stations 933 or 938 may be taken as representing approximately the conditions existing at the mouth of the Ohio River, which is some 30 miles below.

SCHEDULES OF SAMPLE COLLECTIONS AND LABORATORY EXAMINATIONS

The schedule followed in the examination of samples included:

1. Routine examinations, made at all laboratories, namely, bacteriological examinations, turbidity readings, and determinations of alkalinity and dissolved oxygen.
2. Special and less frequent examinations, made only at the Cincinnati laboratory, namely, mineral and sanitary chemical analyses, and microscopic examinations for plankton content. These were not undertaken at the subsidiary laboratories because the work could be more economically handled at one laboratory, thereby saving equipment, and because the results were not materially affected by the delay incident to shipment of the samples to the central laboratory at Cincinnati.

ROUTINE EXAMINATIONS

Samples for routine examination at each laboratory were, so far as possible, collected from each sampling point daily, excepting Sundays and legal holidays. However, at a number of stations collections could be made only three times a week, on alternate days. For instance, at the Wheeling laboratory, where there were

ive sampling stations, Nos. 65, 77, 88, 97, and 104, located at these respective distances, in miles, from Pittsburgh, it was impracticable to make collections from all these stations daily, without employing two motor boats and two attendants for this purpose. Samples were therefore collected one day from stations 65, 77, 88, and 97, and the next day from stations 88, 97, and 104. Similar arrangements were necessary for some of the stations at Pittsburgh and Paducah. Since the results of individual examinations were intended for use only in deriving monthly or weekly averages, it was considered that observations on alternate days would ordinarily give average results comparable to those derived from daily observations. The examinations of these samples included:

1. Bacteriological examinations, consisting of a plate count on gelatin, incubated 48 hours at 20° C.; a plate count on agar, incubated 24 hours at 37° C., and a quantitative fermentation-test for *B. coli*.

2. Turbidity readings. These two examinations, a *turbidity reading* and a threefold *bacteriological examination*, were *invariably* made, and constitute therefore, the *minimum of examinations for all samples*.

3. Determinations of alkalinity, using methyl orange as the indicator, made on all the samples collected from tributaries and those from selected stations on the Ohio in each laboratory district. Additional alkalinity determinations, with phenolphthalein as indicator, were made on samples from the Pittsburgh and Wheeling districts, where special interest attaches to acid pollution. For these daily determinations of alkalinity, "section composite" samples were made up from equal portions of the three samples collected on a cross section.

4. Dissolved oxygen determinations made daily at each laboratory, on samples from *selected* stations. For this determination, duplicate samples were collected at each point on the cross section, one sample being titrated immediately, while the duplicate was incubated 24 hours at 20° C. before titration, in order to determine the oxygen loss.

SPECIAL EXAMINATIONS

1. Samples for organic or *sanitary chemical analysis* were collected once or twice each week from selected stations in each laboratory district, and shipped by express to the Cincinnati laboratory. These samples unless taken from tributaries, where the sampling station included only a single midstream point, were section composites, made up of equal portions from the three points on the cross section. The analysis included, as a minimum, determinations of nitrogen as free and albuminoid ammonia,[5] as nitrates and as nitrites, and of

[5] From Sept. 1, 1914, the determination of nitrogen as albuminoid ammonia was discontinued, and determination of organic nitrogen by the Kjeldahl process substituted.

oxygen consumed (permanganate method), with additional determinations in certain cases.

2. From January to April, 1914, inclusive, the samples used for sanitary chemical analysis were also used for *mineral analysis;* but thereafter samples for mineral analysis were made from selected stations at each laboratory by adding each day an equal portion of water from each of the three points on the sampling section, the amounts added being such as to make a total volume of about two liters at the end of a month. These composite samples were then shipped, each month, to the Cincinnati laboratory for analysis. The analysis included determinations of: Total, volatile and fixed solids; alkalinity (as $CaCO_3$); hardness (as $CaCO_3$) by soap and soda reagents;[6] sulphates; chlorides (as Cl); iron and calcium, with additional special determinations in certain cases.

3. Samples for plankton examination, collected from selected stations at each laboratory at weekly or biweekly intervals, were filtered through a Sedgwick-Rafter filter and the "catch," preserved in 70 per cent alcohol, forwarded to Cincinnati for microscopic examination.[7]

This schedule of examinations, which is repeated in condensed form in the following summary, is shown in full detail in Figures 21, 22, 23, and 24.

SUMMARIZED SCHEDULE OF SAMPLES AND DETERMINATIONS

I. DETERMINATIONS MADE IN ALL LABORATORIES

1. *Bacteriological and turbidity.*—Individual samples from each point, all stations, daily or on alternate days.

2. *Alkalinity* (methyl orange).—Section-composite samples from selected Ohio River stations and from all tributary stations, daily or on alternate days. Additional alkalinity determinations (phenolphthalein), section-composite samples from Allegheny, Monongahela, and Ohio Rivers in Pittsburgh and Wheeling districts.

3. *Dissolved oxygen* (initial and after incubation).—Individual samples in duplicate from each point, majority of Ohio River and tributary sampling stations, daily or on alternate days.

II. SPECIAL DETERMINATIONS, MADE ONLY IN CINCINNATI LABORATORY

1. *Organic (sanitary) chemical analysis.*—Section-composite samples from selected Ohio River stations and all tributary stations, once or twice weekly.

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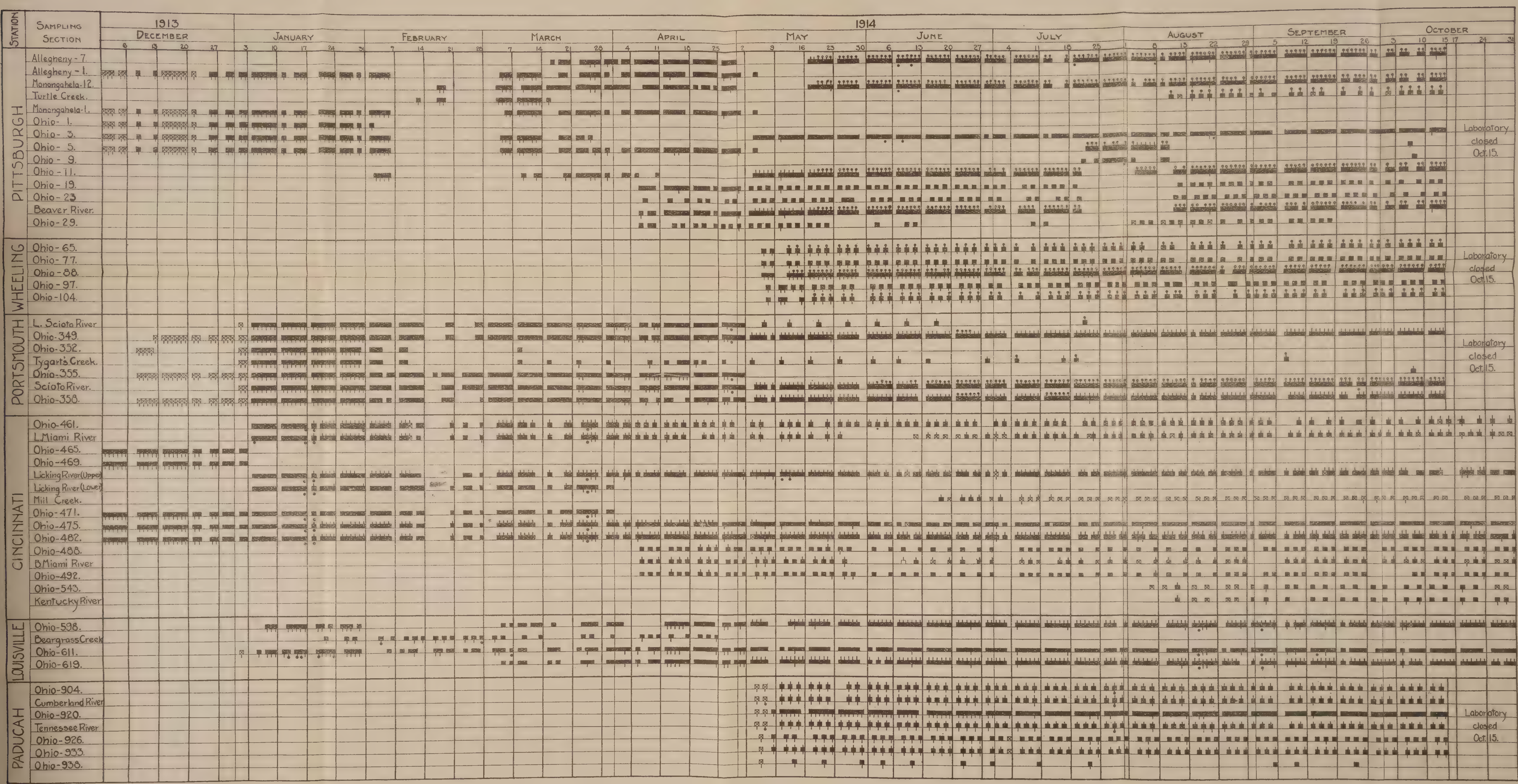
[6] Until July 1, 1914, determinations of hardness were made by the soap method; thereafter by the use of soda reagent, the determinations in both cases being made in accordance with standard practice.

[7] The results of plankton examinations have been fully reported in a previous publication, Public Health Bulletin No. 131, "Studies of the Pollution and Natural Purification of the Ohio River, I," and are therefore not presented in this report.

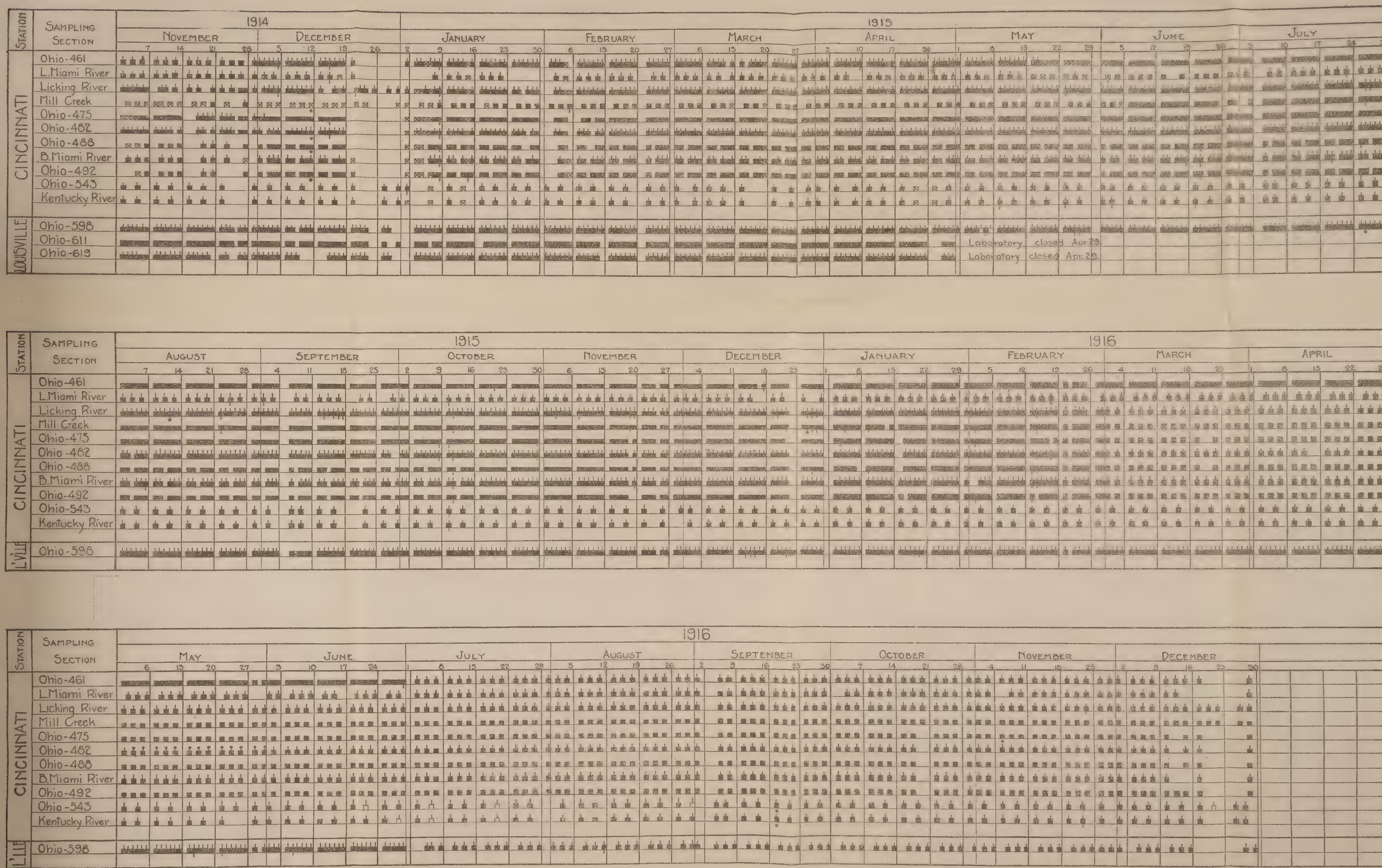


LEGEND.

- □ - Turbidity only.
- ▩ - Bacterial examination only.
- ■ - Bacterial and Turbidity examinations.
- ■ - Bacterial and Turbidity examinations, Gelatin missing.
- ■ - Bacterial and Turbidity examinations, Agar missing.
- ■ - Bacterial and Turbidity examinations, Agar and Gelatin missing.
- ■ - Bacterial and Turbidity examinations, with Methyl Orange Alkalinity determination.
- ■ - Bacterial and Turbidity examinations, with all Alkalinity determinations.

FIG. 21.

CHART
SHOWING
RECORD OF SAMPLES TAKEN FOR ROUTINE EXAMINATIONS
AT
SAMPLING SECTIONS ON OHIO RIVER AND TRIBUTARIES
DECEMBER, 1913 – OCTOBER, 1914.

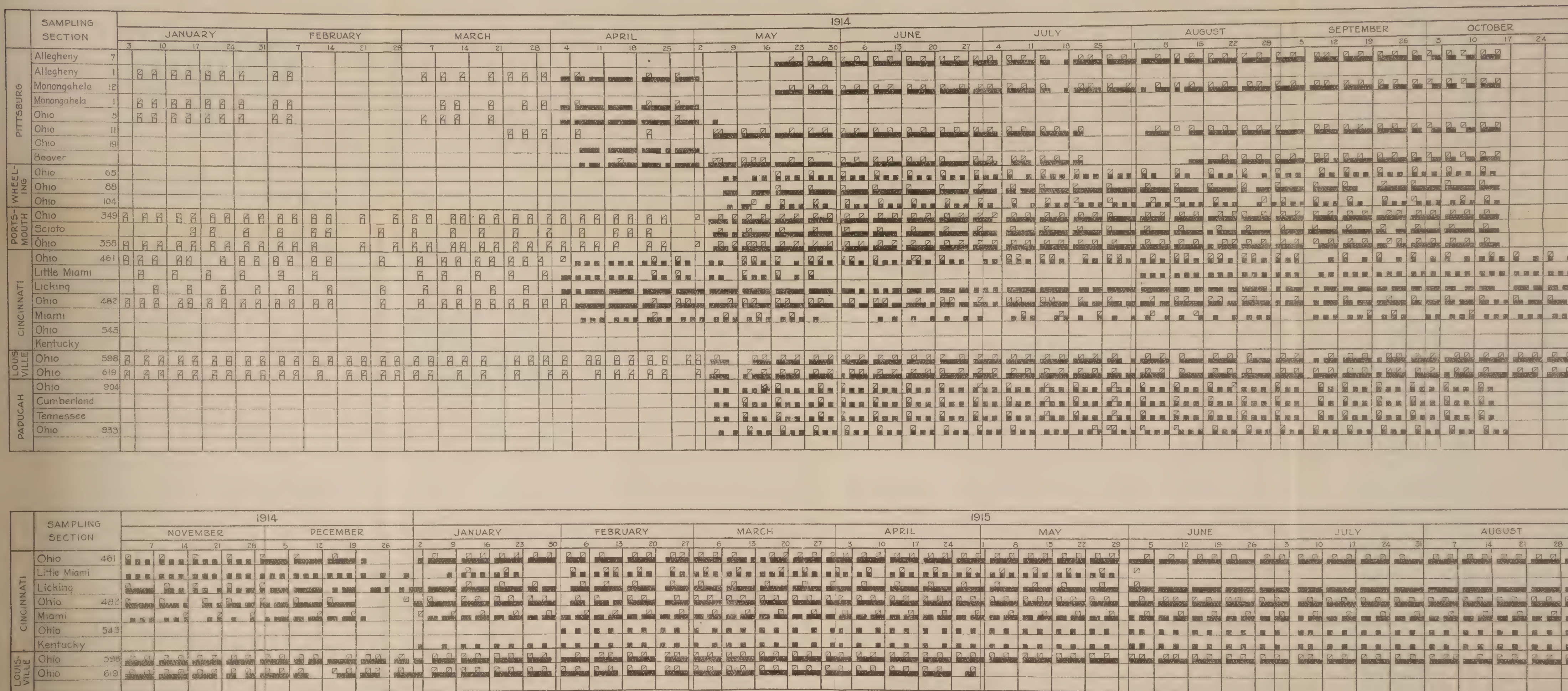


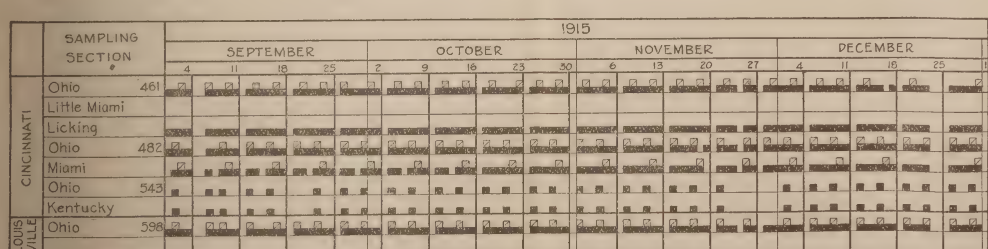
LEGEND

- = Turbidity only.
- = Bacterial examination only.
- = Bacterial and Turbidity examinations
- = Bacterial and Turbidity examinations, Gelatin missing.
- = Bacterial and Turbidity examinations, Agar missing.
- = Bacterial and Turbidity examinations, Agar and Gelatin missing
- = Bacterial and Turbidity examinations, with Methyl Orange Alkalinity determination.
- = Bacterial and Turbidity examinations, with all Alkalinity determinations.

FIG. 22.

CHART
SHOWING
RECORD OF SAMPLES TAKEN FOR ROUTINE EXAMINATIONS
AT
SAMPLING SECTIONS ON OHIO RIVER AND TRIBUTARIES.
NOVEMBER, 1914 - DECEMBER, 1916.





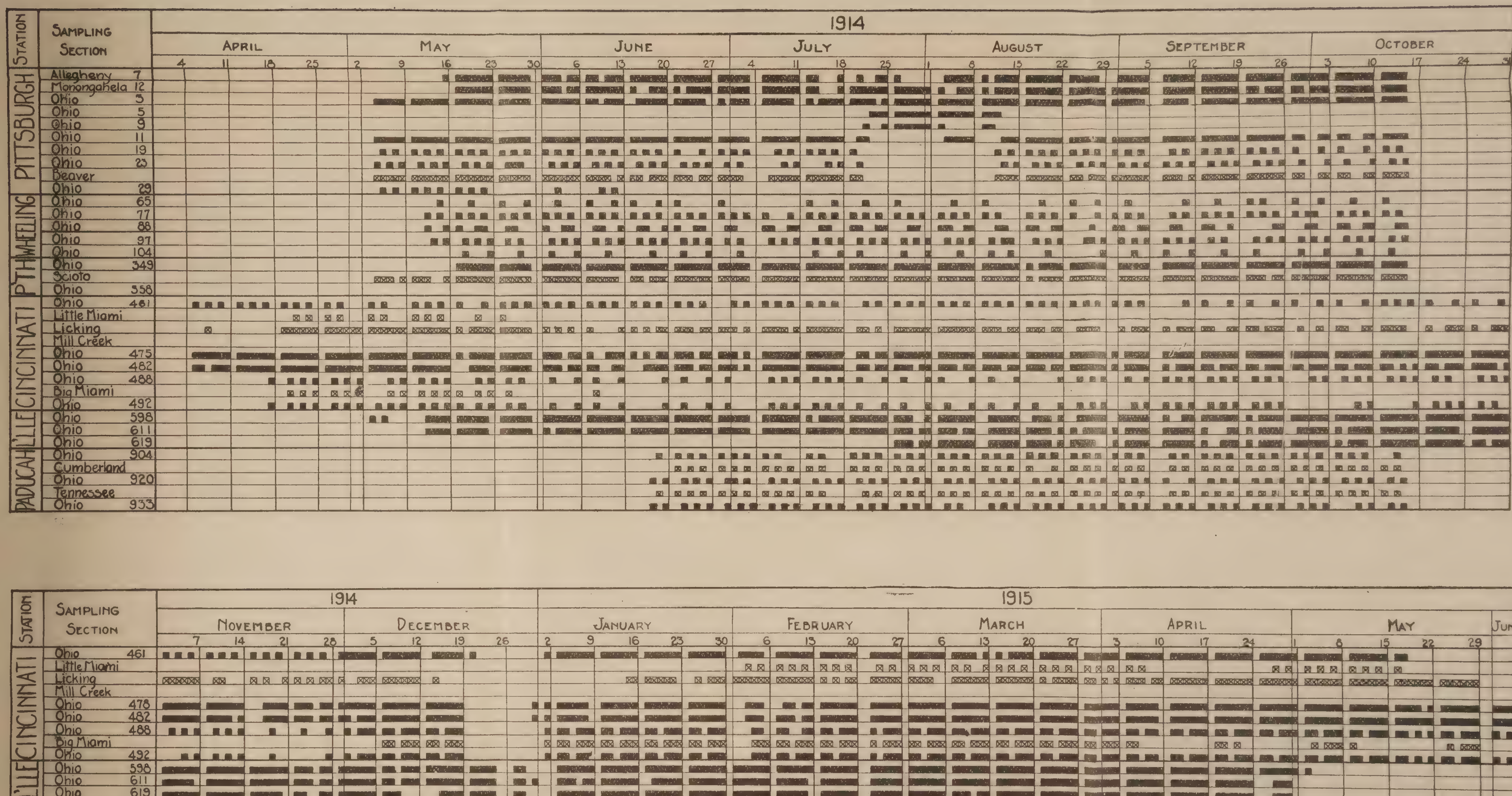
Legend.

- □ Individual Sample – Mineral Analysis
- ▨ Individual Sample – Sanitary Analysis
- ■ Monthly Composite Sample Mineral Analysis

Composite sample made up of portions of each sample collected for bacterial examination

FIG. 23.

CHART
SHOWING
RECORD OF SAMPLES TAKEN FOR CHEMICAL EXAMINATIONS
AT
SAMPLING SECTIONS ON OHIO RIVER AND TRIBUTARIES
JANUARY 1914 – DECEMBER 1915



LEGEND.

■ =Three samples from each section.

⊠ =One sample from each section

Fig. 24.

CHART
SHOWING
RECORD OF SAMPLES TAKEN FOR ROUTINE EXAMINATIONS
AT
SAMPLING SECTIONS ON OHIO RIVER AND TRIBUTARIES.
FOR
DISSOLVED OXYGEN DETERMINATIONS (INITIAL AND AFTER INCUBATION)

APRIL, 1914 - JUNE, 1915.

2. *Mineral analysis.*—From selected stations on the Ohio and from all tributaries. From January 1 to April 30, 1914, same samples as were used for sanitary chemical analysis, thereafter monthly composite samples.

3. *Plankton examinations.*—(*a*) Water samples from single point on section, at selected stations on Ohio River and tributaries, once weekly or once in two weeks. (*b*) Mud samples from single point at selected stations on Ohio River, once or twice monthly.

METHODS USED IN THE COLLECTION AND EXAMINATION OF SAMPLES

A detailed description of the technique used in the collection and examination of samples is given in the appendix, but as the determinations undertaken include only those which are ordinarily made in the sanitary examination of water and sewage, and as the methods used are quite well standardized and generally familiar, such full descriptions as are given there are required chiefly for detailed comparisons with other data and for reference in the future when current practice may have changed. For ordinary interpretation of the data it suffices, perhaps, to state that the observations were made with care, in accordance with established principles, and generally following the technique recommended at that time by the American Public Health Association.[8]

COLLECTION OF SAMPLES

The methods used in the collection of samples for chemical and bacteriological examination require little explanation beyond the description which has already been given of the location of sampling points. During January, February, and March, 1914, samples were taken from near the surface by plunging an open bottle, fixed in a convenient holder, to a depth of about 2 feet. Thereafter samples were uniformly taken at mid-depth. When samples for dissolved oxygen determination as well as for bacteriological examination were required, a specially designed apparatus was used, as described in the appendix. Where only a bacteriological sample was required, it was obtained by lowering a glass-stoppered sterile bottle to the required depth, using a rigid holder with a simple device for opening and closing the bottle.

All sample collections were made at first by technically trained scientific assistants, and were subsequently entrusted to carefully selected attendants only after the latter had been thoroughly instructed and drilled in the technique and had been found to be fully reliable.

[8] The standard reference used was Standard Methods for the Examination of Water and Sewage, Am. Pub. Health Ass'n., Boston, 1912. Three revised editions of this publication have since been issued, in 1917, 1920, and 1923, respectively, altering the recommendations as to some procedures.

As the most important precaution against significant changes in the bacteriological and dissolved oxygen samples between collection and examination, they were delivered at the laboratories and examined as promptly as possible, usually within four hours, often within one or two hours after collection.[9] In warm weather bacteriological samples, as soon as collected, were packed in ice or placed in small refrigerators kept on board the boats, and were kept at a low temperature until delivered and examined. Dissolved oxygen samples were kept at a temperature as near 20° C. as possible. Samples for sanitary chemical analysis, collected at other laboratories and shipped to Cincinnati for examination, were usually received there and analyzed on the day following collection. These samples were not iced, but in warm weather a small amount of chloroform was added for preservation.

TRAINING OF LABORATORY PERSONNEL

At the Cincinnati laboratory, during a part of the period of study, determinations of turbidity, alkalinity, and initial dissolved oxygen content of samples were made on the boat used for sample collections, by the attendant assigned as sample collector. The two attendants to whom this work was entrusted were, however, college students who had received some training in laboratory technique; and before being assigned to this duty they had been carefully drilled and checked in the technique. With this exception, all laboratory examinations were made by technically trained assistants, either medical officers, sanitary engineers, bacteriologists, or chemists.

In order to coordinate and standardize the technique of the various laboratory workers more thoroughly than could be done through written instructions alone, each of them, regardless of previous training, before being assigned to work in a branch laboratory, was given several weeks of special training in the Cincinnati laboratory, checking his technique with that used there. Also, each branch laboratory was frequently inspected by one of the officers from the Cincinnati laboratory, and current results were reported weekly in such detail that irregularities could be promptly discovered and corrected.

LABORATORY METHODS

With the exceptions noted in the detailed description of methods given in the appendix, the technique of bacteriological and chemical examinations followed the recommendations given in Standard Methods for the Examination of Water and Sewage (edition of 1912),

[9] Samples from the Kentucky River and from station No. 543, on the Ohio River just above the junction of the Kentucky, were collected by a local employee, resident in that vicinity, and shipped to Cincinnati by express, in specially designed cases, packed with ice. Under favorable circumstances they reached the laboratory in four to six hours after collection, but were sometimes delayed, in which case they were discarded. Samples from all other stations were brought direct to the laboratories by the messengers who collected them.

supplemented by considerably more detailed written instructions as to minor details of procedure.

All culture media used in bacteriological examinations, and the standard solutions used in making chemical tests, were prepared at the Cincinnati laboratory and shipped to the branch laboratories. Especially in the case of bacteriological culture media this is believed to have been of considerable importance for insuring comparable results.

In the bacteriological examinations the most important departure from Standard Methods, as prescribed in 1912, was in the media and procedures used in quantitative fermentation tests for *B. coli*. These, however, conform quite closely to the standard technique subsequently adopted (in 1917) and at present in general use. Certain slight departures from Standard Methods in the preparation of culture media, which are noted in the appendix, probably had little if any effect upon the end results, except that the nutrient gelatin used for plate counts up to June 30, 1915, probably gave somewhat lower counts than would have been the case had it been made in strict conformity with Standard Methods. Except in the method of preparing gelatin, no changes in bacteriological technique sufficient to impair the comparability of results were made during the period of study.

At the time when this study was begun, the determination of biochemical oxygen demand had not been adopted by the American Public Health Association as a standard procedure, and the method of making this determination had not been fully standardized. The technique of this determination, as described in the appendix is, however, in substantial accordance with the procedure which has subsequently been adopted as standard. Likewise, the use of methyl orange as an indicator in determinations of alkalinity, though not recommended in the Standard Methods of 1912, has been included, since 1917, as a standard procedure.

The most important changes in the procedures of chemical analysis which were made during the course of the study were:

1. The discontinuance, on September 1, 1914, of determinations of albuminoid ammonia, and the adoption, from that date, of the Kjeldahl method for determination of organic ammonia.

2. The change, in July, 1914, from the use of the soap method to the soda reagent method for determinations of hardness, both procedures being in accordance with Standard Methods.

On the whole, it is believed that the results of bacteriological and chemical examinations made at the several laboratories are fully comparable, and are of substantially the same uniformity as if made in a single laboratory. The precision of observations, which depends in part upon considerations other than the care exercised in laboratory technique, is discussed in connection with the results presented in Sections V and VI.

Section V

CHEMICAL ANALYSES

By W. H. Frost and H. W. Streeter

The chemical analyses made in the course of this investigation may be classified into several series, according to the kind and frequency of the determinations made, namely:

1. Determinations of turbidity, made upon all samples delivered to the laboratory for bacteriological examination, as well as upon the less frequent samples collected especially for the purpose of chemical analysis.

2. Determinations of alkalinity, using methyl orange as the indicator, made likewise upon all the samples, bacteriological as well as chemical, delivered from certain sampling stations, including all sampling stations on tributaries and about one-third of those on the Ohio. At stations upon the Allegheny, Monongahela, and upper Ohio parallel determinations of alkalinity were also made, using phenolphthalein as the indicator.

3. More extensive but by no means elaborate mineral analyses, including determinations of: residue on evaporation total, volatile and fixed; total hardness; alkalinity; chlorine, and in some instances of sulphates, calcium and iron. During the early months of the investigation, from January to April, 1914, inclusive, these determinations were made upon the same samples used for organic or "sanitary" chemical analysis. Thereafter, beginning in May, 1914, monthly composite samples were used for mineral analyses. These composite samples were made up by adding to a 2-liter bottle an equal portion from each bacteriological sample collected during the month. By this procedure only one analysis a month was made for each sampling station; but as the sample analyzed was a composite of frequent collections, the result was presumably equivalent to the mean of separate analyses made at each collection.

4. So-called sanitary or organic analyses, comprising determinations of nitrogen in various states of combination and of oxygen consumed by the standard permanganate method. From January to August, 1914, inclusive, nitrogen was determined as free ammonia, albuminoid ammonia, nitrites, and nitrates. Beginning September 1, 1914, the determination of nitrogen as "albuminoid ammonia" was discontinued and the determination of nitrogen by the Kjeldahl

procedure substituted. Samples for organic analysis were collected either once or twice weekly, the schedule varying at different sampling stations.

5. Determinations of dissolved oxygen initially present in samples collected daily or on alternate days from a large majority of the sampling stations, and of the loss in dissolved oxygen in 24 hours' incubation at 20° C. in a sealed container.

The schedule for collection of samples for each of these determinations at each sampling station is shown in detail in figures 21, 22, 23, and 24, and is indicated also in the basic tables presenting the results. The methods used in analysis, in so far as they require any description beyond reference to the current (edition of 1912) Standard Methods for the Examination of Water and Sewage, are also described in a foregoing section, and in the appendix.

The number of analyses made, totaling more than 1,500 organic analyses, and many more determinations of turbidity, alkalinity, and dissolved oxygen, is too great to permit of their presentation in detail, giving the results of each separate analysis. The results are, therefore, presented primarily in the form of monthly averages, in two basic summaries, as follow:

Table No. 50, showing, for each month, the mean results of the organic and mineral analyses made at all stations. Monthly mean temperatures of the water, river stages, and discharges at the various reference gages are also given in this table for convenience of reference. Turbidities and alkalinities as given in this table, except as otherwise noted, are means of determinations made upon the same samples used for sanitary and mineral analyses, and consequently are not identical with the means derived from examination of the more frequent samples collected for bacteriological examination, as given in connection with the latter (in section VI).

Table No. 51, showing, for each month, the results of dissolved oxygen observations at all stations, in terms of initial dissolved oxygen in parts per million, per cent of saturation at the prevailing temperature, saturation deficit in parts per million, loss of oxygen on incubation for 24 hours at 20° C., and total biological oxygen demand as calculated from the other data. These tables show also the mean temperature at each station, and the estimated time of flow, in days, to each station from (*a*) Pittsburgh and (*b*) the station next above.

Additional tables, included in the text of this section, are, for the most part, rearrangements of or derivatives from the data given in these tables. In the latter case the primary data, having been presented in the basic tables, are not repeated.

TABLE No. 50.—*Basic summary of chemical examinations at all sampling stations on the Ohio River and tributaries, by months, 1914 and 1915*

[Terms "daily" or "alternate days" signify exclusive of Sundays and national holidays. Temperature is mean of observations made at time of collection. River stage: "a"= mean of daily gage heights for the entire month; "b"=mean of gage heights on days samples were taken. Both refer to a. m. readings at reference gage for each station. Samples designated thus (*) were samples composited from equal portions taken from three points on cross section]

MONTHLY MEANS (Parts per million)

JANUARY, 1914

Sampling station	Total days samples taken		Mean temperature. °C.	River stage		Mean discharge	Sanitary samples								Mineral samples										
							Turbidity (silica scale)	Nitrogen as—					KMnO₄ oxygen consumed	Biochemical oxygen demand (total)	Residue on evaporation (unfiltered)			Hardness (CaCO₃)			Alkalinity (CaCO₃)	Sulphate (SO₄)	Chlorine (Cl)	Total iron (Fe)	Total calcium (CaCO₃)
																			Soda reagent						
	Sanitary	Mineral		a	b			Total (Kjeldahl)	Free ammonia	Albuminoid ammonia	Nitrites	Nitrates			Total	Volatile	Fixed	By soap, total	Total	Incrustant					
				Feet	Feet	1,000 second-feet																			
Allegheny-1	7	7	0.6	6.6	5.1	21.8	30	----	0.105	0.115	0.003	0.37	3.22	----	182	47	135	47	----	----	13	----	14.5	6.4	----
Monongahela-1	7	7	.6	5.8	5.4	17.0	80	----	.021	.202	.002	.33	3.89	----	199	47	152	84	----	----	−3	----	4.8	11.2	----
5	7	7	.6	5.8	5.6	38.8	58	----	.063	.169	.003	.41	3.80	----	180	43	137	47	----	----	5	----	11.5	7.6	----
349	9	9	2.5	18.5	18.6	90.8	96	----	.035	.142	.002	.48	3.91	----	211	53	158	61	----	----	22	----	15.1	6.8	----
Scioto	3	3	2.3	2.2	3.0	5.05	63	----	.089	.241	.006	1.45	4.24	----	350	112	238	201	----	----	153	----	7.3	2.6	----
358	9	9	2.5	18.5	18.6	95.8	95	----	.032	.159	.003	.54	4.19	----	214	49	165	63	----	----	22	----	15.1	6.3	----
461	8	8	2.0	20.0	20.7	94.9	113	----	.056	.157	.002	.44	4.47	----	239	58	181	63	----	----	29	----	13.6	8.5	----
Little Miami	4	4	2.1	----	----	1.41	49	----	.056	.138	.004	1.30	4.42	----	305	107	198	237	----	----	179	----	5.2	2.3	----
Licking	4	4	3.4	3.7	3.2	3.37	79	----	.042	.122	.002	1.34	2.52	----	225	83	142	126	----	----	100	----	4.1	4.0	----
482	9	9	2.0	20.0	20.3	99.7	104	----	.050	.165	.002	.44	4.20	----	245	62	183	66	----	----	31	----	14.2	8.9	----
598	9	9	2.1	17.6	17.7	108.0	130	----	.043	.151	.005	.65	4.28	----	256	60	196	80	----	----	43	----	14.0	6.0	----
619	9	9	1.8	17.6	17.7	108.0	142	----	.033	.190	.005	.60	4.82	----	285	64	221	78	----	----	42	----	14.8	8.1	----

FEBRUARY, 1914

Sampling station	Sanitary	Mineral	Mean temperature. °C.	a	b	Mean discharge	Turbidity (silica scale)	Total (Kjeldahl)	Free ammonia	Albuminoid ammonia	Nitrites	Nitrates	KMnO₄ oxygen consumed	Biochemical oxygen demand (total)	Residue Total	Residue Volatile	Residue Fixed	By soap, total	Soda reagent Total	Soda reagent Incrustant	Alkalinity (CaCO₃)	Sulphate (SO₄)	Chlorine (Cl)	Total iron (Fe)	Total calcium (CaCO₃)
Allegheny-1	2	2	2.0	11.3	14.9	25.6	60	----	0.013	0.182	0.002	0.60	4.90	----	155	37	118	35	----	----	8	----	7.5	8.7	----
Monongahela-1	2	2	2.0	6.4	12.8	16.6	45	----	.005	.099	.003	.48	3.04	----	143	25	118	60	----	----	−2	----	4.9	8.4	----
5	2	2	2.0	6.4	12.8	42.2	74	----	.012	.193	.005	.53	5.32	----	165	34	131	36	----	----	7	----	8.0	9.0	----
349	6	6	1.8	25.1	27.1	138.0	227	----	.021	.244	.004	.52	6.39	----	339	55	284	47	----	----	18	----	9.9	15.6	----
Scioto	4	4	1.8	5.5	5.7	14.2	405	----	.066	.421	.013	2.00	7.90	----	445	114	331	158	----	----	112	----	5.6	12.4	----

358	5	5	2.2	25.1	27.6	152.2	253	----	.037	.282	.003	.56	7.02	----	363	54	309	54	----	----	18	----	9.2	17.9	----
461	5	5	2.8	28.3	29.9	156.1	213	----	.018	.224	.002	.69	6.07	----	300	57	243	57	----	----	29	----	9.1	13.4	----
Little Miami	2	2	2.4	----	----	3.68	395	----	.051	.453	.014	1.55	7.70	----	379	109	270	170	----	----	130	----	4.8	9.3	----
Licking	3	3	2.7	8.1	5.4	13.2	335	----	.031	.242	.002	1.88	5.40	----	356	84	272	99	----	----	84	----	3.7	14.6	----
482	5	5	2.6	28.3	30.4	173.0	270	----	.022	.266	.003	.67	6.29	----	460	73	387	60	----	----	28	----	9.7	16.0	----
598	8	8	1.4	29.1	29.0	221.0	479	----	.037	.542	.008	1.32	10.29	----	669	104	565	99	----	----	65	----	9.8	29.2	----
619	7	7	1.5	29.1	29.5	221.0	529	----	.043	.494	.008	.73	8.58	----	631	83	548	63	----	----	41	----	7.8	27.7	----

MARCH, 1914

Allegheny-1	7	7	2.7	12.8	12.6	37.0	28	----	0.056	0.143	0.003	0.35	3.70	----	228	49	179	61	----	----	11	----	7.7	9.1	----
Monongahela-1	5	5	4.5	7.7	9.6	20.2	43	----	.013	.160	.004	.27	3.40	----	206	44	162	69	----	----	3	----	5.2	5.5	----
5	4	4	1.2	7.7	6.2	57.2	44	----	.029	.168	.004	.40	3.40	----	193	37	156	66	----	----	8	----	10.4	4.3	----
11	3	3	4.5	7.7	10.6	57.2	15	----	.023	.224	.003	.22	4.10	----	233	57	176	64	----	----	2	----	4.7	10.6	----
349	9	9	4.6	24.5	23.3	133.0	107	----	.077	.210	.003	.46	4.40	----	291	60	231	60	----	----	21	----	10.9	6.6	----
Scioto	5	5	4.4	7.2	8.2	19.1	230	----	.144	.369	.009	1.55	6.40	----	367	102	265	103	----	----	88	----	5.6	15.2	----
358	9	9	3.4	24.5	23.3	152.1	115	----	.028	.239	.004	.49	4.70	----	274	49	225	64	----	----	24	----	9.2	5.9	----
461	9	9	3.1	27.0	26.6	147.7	113	----	.039	.172	.004	.65	4.20	----	280	58	222	74	----	----	31	----	7.5	9.4	----
Little Miami	5	5	5.6	----	----	5.47	125	----	.073	.254	.008	1.28	4.80	----	341	104	237	153	----	----	123	----	7.0	6.8	----
Licking	4	4	4.2	5.5	5.0	6.83	122	----	.047	.205	.005	1.44	3.50	----	329	72	257	106	----	----	77	----	6.8	6.2	----
482	9	9	3.1	27.0	26.6	160.0	120	----	.030	.228	.006	.60	4.70	----	299	60	239	66	----	----	31	----	8.7	8.7	----
598	8	8	3.7	26.4	25.6	192.0	175	----	.040	.264	.005	.89	5.10	----	336	70	296	74	----	----	49	----	7.1	11.6	----
619	6	6	3.5	26.4	26.2	192.0	234	----	.062	.282	.005	.93	6.30	----	429	77	352	81	----	----	50	----	6.7	11.0	----

APRIL, 1914

Allegheny-1	3	23	9.7	11.5	11.7	48.1	82	----	0.026	0.207	0.002	0.48	3.90	----	195	76	119	39	----	----	11	----	8.1	3.0	----
Monongahela-1	3	23	11.0	11.0	11.8	31.1	78	----	.016	.203	.002	.42	3.10	----	108	46	62	47	----	----	5	----	5.7	4.0	----
5	1	24	14.5	11.0	14.2	79.2	195	----	.006	.210	.003	.25	5.50	----	226	116	110	47	----	----	4	----	6.3	4.2	----
11	2	2	8.8	11.0	10.6	79.2	35	----	.015	.185	.003	.48	2.90	----	120	22	98	97	----	----	1	----	2.8	----	----
19	----	19	16.3	11.0	10.3	79.2	----	----	----	----	----	----	----	----	182	43	139	47	----	----	3	----	8.4	4.0	----
Beaver	1	18	15.0	----	----	11.8	240	----	.030	.270	.004	.25	7.30	----	231	51	180	65	----	----	11	----	18.1	1.0	----
349	7	7	9.5	34.3	34.9	210.0	110	----	.012	.201	.005	.37	3.50	----	244	38	206	50	----	----	16	----	7.3	6.6	----
Scioto	4	4	10.5	6.1	4.6	17.2	87	----	.045	.195	.015	1.35	3.20	----	323	84	239	179	----	----	132	----	4.5	4.0	----
358	6	6	10.0	34.3	36.5	227.2	128	----	.008	.212	.004	.44	4.10	----	239	46	193	49	----	----	19	----	6.3	6.7	----
461	3	14	11.6	36.3	36.8	237.1	153	----	.042	.210	.003	.32	4.60	----	500	300	200	52	54	26	28	----	7.4	7.9	----
Little Miami	2	13	17.5	----	----	5.16	50	----	.045	.160	.005	.63	4.90	----	454	202	252	228	----	----	169	----	3.8	----	----
Licking	3	23	17.0	5.0	4.5	5.67	137	----	.026	.180	.002	.40	5.70	----	222	127	95	89	----	----	79	----	2.5	----	----
482	4	25	12.6	36.3	35.2	248.0	125	----	.024	.323	.003	.43	6.60	----	230	55	175	57	42	19	23	----	5.4	11.0	----
Miami	1	11	----	5.4	3.8	14.3	----	----	.102	.170	.016	1.60	----	----	441	127	314	191	----	----	196	----	7.4	----	----
598	8	8	10.1	36.0	36.2	297.0	201	----	.020	.243	.006	.51	5.00	----	356	96	260	78	----	----	41	----	6.6	7.6	----
619	6	6	9.9	36.0	36.2	297.0	134	----	.022	.228	.005	.78	4.40	----	372	150	222	84	----	----	40	----	7.6	7.6	----

TABLE No. 50.—*Basic summary of chemical examinations at all sampling stations on the Ohio River and tributaries, by months, 1914 and 1915*—Continued

MONTHLY MEANS (Parts per million)—Continued

MAY, 1914

Sampling station	Total days samples taken: Sanitary	Total days samples taken: Mineral	Mean temperature. °C.	River stage: a	River stage: b	Mean discharge	Sanitary samples: Turbidity (silica scale)	Nitrogen as—: Total (Kjeldahl)	Nitrogen as—: Free ammonia	Nitrogen as—: Albuminoid ammonia	Nitrogen as—: Nitrites	Nitrogen as—: Nitrates	KMnO4 oxygen consumed	Biochemical oxygen demand (total)	Mineral samples: Residue on evaporation (unfiltered): Total	Residue: Volatile	Residue: Fixed	Hardness ($CaCO_3$): By soap, total	Hardness: Soda reagent: Total	Hardness: Soda reagent: Incrustant	Alkalinity ($CaCO_3$)	Sulphate (SO_4)	Chlorine (Cl)	Total iron (Fe)	Total calcium ($CaCO_4$)
				Feet	*Feet*	*1,000 second-feet*																			
Allegheny-7	3	11	20.2	10.2	(1)	32.8			0.188	0.160	0.002	0.08	3.65	2.18	240	138	102	44	60	42	18		8.2	0.8	
Monongahela-12	3	11	24.0	6.9	3.3	9.40			.011	.300	.002	.24	2.10	1.31	322	60	262	129	108	94	14		8.0	3.0	
11	*7	*22	16.9	6.9	6.1	42.2			.082	.190	.002	.19	3.45	5.10	258	18	240	49	58	49	9		10.0	2.9	
Beaver	7	24	16.0			7.48			.094	.240	.009	.46	3.84	5.53	359	102	257	75	90	59	31		29.5	6.0	
65	*2	*10	16.0	11.4	9.6	55.7			.057	.160	.003	.15	3.23	4.70	226	32	194	55	58	42	16		10.2	4.0	
88	*2	*18	15.5	11.4	9.6	55.7			.081	.145	.004	.18	3.73	7.13				49	50	32	18				
104	*3	*9	16.7	11.4	10.7	55.7			.070	.140	.004	.40	2.50	5.05	190	44	146	60	55	34	21			2.3	
349	*9	*24	17.1	20.0	20.9	101.0			.014	.230	.001	.24	4.51	1.21	259	51	208	57	53	28	25		10.0	4.0	
Scioto	4	23	18.9	2.8	2.8	6.95			.034	.340	.007	.66	5.20	2.92	425	61	364	166	195	34	151		7.8	4.4	
358	*10	*23	17.4	20.0	20.5	108.0			.012	.216	.001	.27	5.60		268	26	242	168	77	44	33		11.8	6.0	
461	*5	*10	17.7	22.8	22.8	120.2			.014	.220	.002	.20	3.87	2.24	304	49	255	62	65	33	32		12.5	5.8	
Little Miami	3	8	19.7			1.83			.016	.270	.009	.50	4.82	3.84	411			215	220	38	182		5.2	2.0	
Licking	4	25	18.4	3.9	5.3	4.00			.017	.260	.002	.38	3.80	5.34	345	31	314	75	88	16	72		4.0	7.0	
482	*7	*25	17.2	22.8	23.7	126.0			.014	.260	.002	.29	3.50	4.13	376	50	326	55	68	31	37		10.0	4.0	
Miami	3	11	16.4	3.5	3.5	4.43			.010	.220	.008	.70	4.00	4.76	476	121	355	243	243	36	207		4.7	4.4	
598	*8	*20	17.1	21.4	21.7	147.0			.055	.230	.003	.29	4.38	3.40	323	80	243	60	53	11	42		6.9	7.0	
619	*8	*22	17.5	21.4	21.8	147.0			.032	.250	.002	.30	3.98		297	55	242	62	60	19	41		5.2	4.0	
904	*3	*10	19.8	18.5	17.6	210.0			.014	.330	.003	.40	4.32		448	89	359	94	88	23	65		7.9	5.8	
Cumberland	3	10	20.7	12.9	12.7	25.3			.034	.340	.005	.45	4.00		446	50	396	70	74	6	68		2.2	3.6	
Tennessee	3	11	22.2	6.3	5.1	44.0			.108	.170	.005	.08	1.60		224	67	157	60	43		50		4.8		
933	*3		19.3	18.5	18.0	279.3			.056	.290	.002	.37	5.20												

JUNE, 1914

Allegheny-7	9	11	23.5	3.6	3.5	6.53	-----	-----	0.165	0.150	0.002	0.10	2.82	1.51	240	138	102	44	60	42	18	-----	8.2	0.8	-----
Monongahela-12	9	26	24.2	5.8	5.9	2.85	-----	-----	.011	.300	.002	.24	2.10	1.31	376	66	310	146	175	175	−20	150	10.5	1.8	-----
11	*9	*26	23.8	5.8	5.9	9.38	-----	-----	.167	.340	.005	.14	2.49	2.08	288	52	236	91	106	98	8	95	18.0	4.0	-----
Beaver	9	26	23.3	-----	-----	.850	-----	-----	.498	.240	.051	.25	2.63	2.38	356	86	270	114	149	107	42	81	71.5	2.0	-----
65	*5	*13	23.1	6.1	6.3	10.3	-----	-----	.206	.180	.008	.30	3.11	2.52	256	78	178	81	125	111	14	52	25.5	1.0	-----
88	*5	*26	23.6	6.1	6.3	10.3	-----	-----	.214	.180	.011	.31	3.41	3.64	288	70	218	100	120	108	12	51	24.5	1.0	-----
104	*5	*13	23.1	6.1	6.1	10.3	-----	-----	.218	.230	.007	.22	2.23	3.45	330	76	254	94	115	101	14	54	24.0	3.0	-----
349	*9	*26	25.1	5.8	5.9	17.9	-----	-----	.009	.130	.003	.23	1.58	2.04	262	79	183	97	115	71	144	31	31.5	.8	-----
Scioto	5	25	24.3	.14	.16	1.00	-----	-----	.013	.270	.005	.20	3.18	5.00	455	137	318	166	260	45	215	25	16.0	2.5	-----
358	*9	*25	25.4	5.8	5.9	18.9	-----	-----	.087	.140	.002	.18	1.60	-----	276	78	198	111	127	63	64	24	25.0	.5	-----
461	*6	*12	25.4	7.2	7.6	19.8	-----	-----	.002	.140	.002	.18	1.78	2.43	236	62	174	103	113	54	59	23	25.5	.5	-----
Licking	4	19	26.5	2.0	2.0	1.03	-----	-----	.020	.220	.012	.60	14.95	4.76	802	108	694	91	125	44	81	-----	5.0	20.0	-----
482	*7	*23	25.6	7.2	6.9	21.0	-----	-----	.033	.200	.006	.22	4.04	4.42	356	90	266	114	125	60	65	25	25.0	5.9	-----
598	*9	*26	25.5	6.9	6.9	28.8	-----	-----	.118	.180	.012	.27	2.29	4.61	264	80	184	109	133	60	73	17	23.0	2.5	-----
619	*9	*24	26.0	6.9	6.9	28.8	-----	-----	.079	.230	.021	.26	3.44	-----	274	88	186	121	126	56	70	18	18.0	2.3	-----
904	*5	*13	26.9	6.0	6.4	46.6	-----	-----	.091	.180	.006	.20	4.34	1.94	262	76	186	140	143	39	104	Tr.	14.0	1.6	-----
Cumberland	5	13	29.3	17.9	7.7	4.54	-----	-----	.045	.16	.002	.49	4.10	0.00	-----	-----	-----	83	110	23	87	Tr.	5.0	1.7	-----
Tennessee	5	13	29.7	2.1	2.1	17.1	-----	-----	.086	.190	.003	.12	4.20	1.26	309	58	251	-----	92	3	89	-----	4.0	4.5	49
933	*5	-----	27.5	6.0	30.3	68.2	-----	-----	.097	.160	.001	.16	4.62	3.74	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

JULY, 1914

Allegheny-7	8	23	25.0	2.1	2.0	3.46	-----	-----	0.117	0.150	0.002	0.16	3.00	1.60	227	56	171	-----	89	73	16	102	24.0	0.5	65
Monongahela-12	8	23	25.0	6.1	5.9	1.92	-----	-----	.021	.240	.001	.18	2.90	2.09	435	54	381	-----	121	121	−6	138	11.0	.9	42
5	2	-----	28.0	6.1	6.4	5.38	-----	-----	.362	.180	.014	.15	3.70	2.14	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
11	*6	*17	25.0	6.1	5.8	5.38	-----	-----	.267	.150	.011	.23	1.80	1.99	252	58	194	-----	115	110	5	105	21.0	.2	-----
Beaver	6	15	24.0	.68	.71	.460	-----	-----	.266	.200	.034	.37	2.70	3.11	497	125	372	-----	153	116	37	115	108.0	1.1	133
65	*4	*13	25.0	7.8	8.3	6.63	-----	-----	.282	.190	.007	.30	2.80	1.16	262	84	178	-----	120	113	7	105	25.5	.5	82
88	*4	*25	26.0	7.8	8.4	6.63	-----	-----	.213	.160	.009	.34	2.50	2.38	285	68	217	-----	121	114	7	115	27.0	.8	84
104	*4	*11	25.0	7.8	8.5	6.63	-----	-----	.279	.140	.008	.29	2.90	1.51	276	70	206	-----	119	111	8	149	27.0	.2	91
349	*8	*26	27.0	5.4	6.6	16.4	-----	-----	.041	.210	.012	.35	2.90	1.85	322	84	238	-----	95	57	38	64	35.0	1.8	89
Scioto	4	26	26.0	−.10	−.10	.730	-----	-----	.099	.320	.007	.19	4.00	4.37	380	100	280	-----	152	-----	189	75	20.0	1.4	144
358	*8	*26	26.7	5.4	5.7	17.1	-----	-----	.027	.140	.011	.37	2.50	-----	314	91	213	-----	133	76	57	94	32.5	1.7	90
461	*7	*13	27.5	6.7	6.5	18.7	-----	-----	.003	.130	.005	.27	2.20	1.94	286	89	197	-----	105	50	55	84	37.5	.5	97
Licking	4	23	26.5	2.0	2.0	1.03	-----	-----	.020	.220	.012	.60	14.95	4.76	159	35	124	-----	100	12	88	110	7.0	1.2	79
482	*6	*22	26.8	6.7	6.6	19.0	-----	-----	.062	.150	.013	.32	2.40	3.93	299	80	219	-----	138	80	58	80	36.0	.4	96
Miami	3	8	25.0	2.5	2.3	1.00	-----	-----	.050	.330	.010	.43	4.50	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
598	*8	*24	27.0	6.0	6.1	23.1	-----	-----	.071	.230	.020	.21	3.00	4.90	316	90	226	-----	155	81	74	68	39.0	.2	78
619	*8	*25	27.2	6.0	6.1	23.1	-----	-----	.062	.210	.020	.21	3.30	4.76	320	94	226	-----	148	78	70	70	42.5	.4	106
904	*4	*14	28.3	4.4	4.4	30.8	-----	-----	.057	.200	.002	.06	5.00	1.55	308	90	218	-----	164	42	122	54	24.5	.6	99
Cumberland	4	14	28.3	8.7	8.8	8.00	-----	-----	.099	.37	.013	.40	3.60	1.26	309	58	251	-----	92	3	89	-----	4.0	4.5	49
Tennessee	4	14	30.7	2.2	1.8	19.2	-----	-----	.104	.160	.001	.13	3.20	0.87	309	58	251	-----	92	3	89	-----	4.0	4.5	49
933	*4	-----	29.2	4.4	4.7	58.0	-----	-----	.042	.250	.002	.21	3.00	1.36	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

[1] No gage readings available from May 20 to 30, 1914.

TABLE No. 50.—*Basic summary of chemical examinations at all sampling stations on the Ohio River and tributaries, by months, 1914 and 1915*—Continued

MONTHLY MEANS (Parts per million)—Continued

AUGUST, 1914

Sampling station	Total days samples taken: Sanitary	Total days samples taken: Mineral	Mean temperature, °C.	River stage: a	River stage: b	Mean discharge	Sanitary samples: Turbidity (silica scale)	Nitrogen as—: Total (Kjeldahl)	Nitrogen as—: Free ammonia	Nitrogen as—: Albuminoid ammonia	Nitrogen as—: Nitrites	Nitrogen as—: Nitrates	$KMnO_4$ oxygen consumed	Biochemical oxygen demand (total)	Mineral samples: Residue on evaporation (unfiltered): Total	Residue: Volatile	Residue: Fixed	Hardness ($CaCO_3$): By soap, total	Hardness: Soda reagent: Total	Hardness: Soda reagent: Incrustant	Alkalinity ($CaCO_3$)	Sulphate (SO_4)	Chlorine (Cl)	Total iron (Fe)	Total calcium ($CaCO_3$)
				Feet	*Feet*	*1,000 second-feet*																			
Allegheny-7	8	25	23.6	1.4	1.5	1.66	----	----	0.212	0.140	0.004	0.16	3.37	1.89	304	72	232	----	128	119	9	105	35.0	0.8	95
Monongahela-12	8	23	24.6	6.0	6.0	2.07	----	----	.009	.410	.001	.07	3.50	3.45	324	88	236	----	138	138	−16	145	12.5	.8	84
11	*8	*21	24.5	6.0	6.0	3.73	----	----	.396	.360	.023	.23	3.75	2.48	340	96	244	----	139	136	3	104	28.0	.5	----
Beaver	4	16	22.3	.48	.76	.360	----	----	.840	.240	.063	.32	2.80	2.52	641	213	428	----	222	197	25	100	141.0	.9	165
65	*5	*10	24.4	8.2	7.9	4.65	----	----	.458	.190	.010	.29	2.21	1.36	346	70	276	----	136	127	9	105	35.5	.8	102
88	*5	*23	24.8	8.2	7.9	4.65	----	----	.473	.170	.006	.35	3.09	2.43	342	90	250	----	139	132	7	107	32.5	1.8	102
104	*4	*12	24.2	8.2	8.2	4.65	----	----	.471	.200	.008	.31	3.19	1.70	356	86	270	----	130	125	5	98	30.0	2.0	104
349	*8	*25	25.8	4.0	3.7	11.8	----	----	.020	.210	.005	.26	5.02	1.80	326	90	236	----	110	91	39	58	33.0	2.6	86
Scioto	4	24	25.1	−.10	−.35	.960	----	----	.035	.280	.006	.14	4.40	4.03	523	175	348	----	209	15	184	53	27.5	5.0	144
358	*8	*25	25.8	4.0	3.8	12.8	----	----	.021	.170	.005	.27	4.14	----	257	99	178	----	122	62	60	66	31.0	5.9	90
461	*8	*13	26.5	5.7	5.6	13.9	----	----	.022	.190	.004	.28	3.36	2.38	378	100	278	----	102	60	42	63	29.5	4.2	90
Little Miami	----	13	----	6.4	6.2	.550	----	----	----	----	----	----	----	----	568	----	----	----	165	12	153	36	12.0	8.7	114
Licking	4	23	26.9	1.8	1.6	.740	----	----	.030	.510	.029	.80	5.06	4.90	552	----	----	----	92	7	85	Tr.	7.5	10.5	82
482	*7	*23	26.1	5.7	5.2	15.2	----	----	.161	.170	.019	.23	2.77	3.59	370	----	----	----	124	61	63	47	27.5	6.6	94
Miami	2	10	----	2.5	2.2	1.27	----	----	.027	.280	.022	.43	3.25	----	792	----	----	----	202	50	152	41	11.0	18.1	156
598	*6	*24	26.3	5.1	4.4	18.3	----	----	.050	.250	.020	.29	3.53	1.60	266	94	172	----	119	46	73	60	26.0	.8	57
619	*6	*23	27.0	5.1	4.4	18.3	----	----	.053	.290	.024	.28	4.07	2.91	166	100	66	----	128	54	74	42	26.0	.9	87
904	*5	*13	27.9	2.5	2.8	26.4	----	----	.068	.450	.008	.11	3.23	.78	292	114	178	----	146	43	103	51	25.5	1.4	103
Cumberland	5	13	28.3	8.5	9.1	6.88	----	----	.012	.170	.014	.58	2.80	.87	244	56	188	----	78	0	80	Tr.	5.0	5.8	72
Tennessee	4	13	28.4	2.0	2.0	16.7	----	----	.017	.180	.004	.31	2.84	1.17	184	50	134	----	60	10	50	Tr.	9.5	4.0	47
933	*4	*13	28.0	2.5	2.3	50.0	----	----	.051	.230	.003	.19	4.03	1.46	246	76	170	----	108	24	84	----	----	2.4	----

SEPTEMBER, 1914

Allegheny-7	8	24	18.9	1.6	1.6	2.25	-	-	0.122	0.190	0.003	0.13	4.48	2.24	250	78	172	-	98	73	25	83	28.0	1.5	76
Monongahela-12	8	23	21.0	6.0	6.0	1.12	-	-	.048	.430	.002	.15	3.51	2.67	365	80	285	-	175	175	−16	194	15.0	2.7	98
11	*7	*24	19.7	6.0	6.0	3.37	-	-	.466	.430	.015	.19	3.96	2.14	280	76	204	-	120	103	17	99	29.5	.5	-
Beaver	8	23	19.4	.53	.51	.390	-	-	.481	.270	.048	.31	3.33	1.31	556	196	360	-	210	179	31	99	111.0	1.8	135
65	*4	*12	19.6	8.0	7.8	4.50	-	-	.380	.190	.006	.25	3.23	1.12	326	86	240	-	120	104	16	107	37.0	2.0	91
88	*4	*23	20.4	8.0	7.9	4.50	-	-	.304	.180	.005	.20	3.84	2.82	342	90	250	-	139	132	7	107	32.5	1.8	102
104	*5	*12	20.2	8.0	8.1	4.50	-	-	.294	.260	.006	.26	3.33	2.58	372	108	264	-	144	135	9	120	42.5	1.6	108
349	*9	*25	22.4	4.6	4.9	13.7	-	-	.024	.290	.011	.32	3.91	1.46	458	224	234	-	125	85	37	71	37.5	2.9	90
Scioto	5	24	21.4	−.07	+.08	.810	-	-	.034	.340	.013	.35	4.41	3.84	428	137	291	-	232	41	191	45	16.0	1.0	152
358	*9	*22	21.9	4.6	4.9	14.5	-	-	.027	.210	.008	.29	3.98	-	366	90	276	-	142	86	56	66	42.0	2.5	96
461	*4	*8	21.9	6.2	6.0	17.1	-	-	.016	.220	.005	.36	3.45	2.14	444	122	322	-	128	81	47	64	44.5	7.0	95
Little Miami	-	12	-	5.9	5.8	.160	-	-	-	-	-	-	-	-	326	80	246	-	205	24	181	45	8.5	1.0	63
Licking	3	20	21.3	1.4	1.3	.230	-	-	.015	.220	.016	.23	4.08	3.55	374	90	284	-	-	-	90	-	-	9.0	96
482	*4	*20	21.7	6.2	6.0	17.5	-	-	.021	.230	.013	.46	3.35	3.59	370	134	236	-	130	77	53	63	46.0	3.5	103
Miami	2	9	22.5	2.4	2.2	.840	-	-	.018	.420	.008	.50	3.90	-	454	162	292	-	240	25	215	52	14.0	3.5	167
598	*8	*23	23.0	5.5	5.5	20.9	-	-	.044	.240	.030	.33	4.11	2.52	356	116	240	-	132	70	62	57	37.0	8.0	102
619	*9	*23	23.2	5.5	5.7	20.9	-	-	.024	.260	.029	.31	4.36	3.35	366	126	246	-	98	34	64	55	36.5	6.7	100
904	*4	*12	23.5	4.6	4.2	37.3	-	-	.040	.300	.018	.34	4.43	1.21	544	146	398	-	128	39	89	53	21.5	8.3	102
Cumberland	4	12	24.9	8.4	7.8	6.84	-	-	.024	.33	.009	.54	4.13	1.55	538	96	432	-	85	8	78	Tr.	4.5	9.4	77
Tennessee	5	12	25.1	1.5	1.4	15.9	-	-	.016	.170	.003	.20	3.53	.78	294	90	204	-	68	7	61	Tr.	9.5	5.7	59
933	*5	*13	24.2	4.6	4.5	60.1	-	-	.093	.500	.018	.24	3.76	1.46	454	110	344	-	115	34	81	-	15.0	7.6	93

PERIOD OCT. 1-15, 1914 [2]

Allegheny—7	5	10	17.0	0.9	0.9	0.840	-	0.99	-	-	0.006	0.20	3.36	1.12	332	80	252	-	138	121	17	90	41.5	0.8	95
Monongahela—12	5	10	19.6	6.1	6.1	.830	-	1.10	-	-	.001	.15	2.17	1.70	490	98	392	-	231	231	−15	300	24.0	7.6	144
11	5	*10	18.4	6.1	6.1	1.67	-	1.46	-	-	.026	.15	2.70	1.31	364	90	274	-	156	135	21	145	39.5	.2	-
Beaver	5	10	16.6	.25	.31	.240	-	.74	-	-	.054	.31	3.26	2.04	576	150	426	-	224	198	26	175	114.0	4.0	186
65	2	*6	17.8	7.8	7.8	2.47	-	.80	-	-	.016	.40	3.10	2.14	282	56	226	-	122	100	22	83	38.5	1.0	112
88	2	*13	19.0	7.8	7.8	2.47	-	.77	-	-	.007	.28	5.42	1.65	299	62	237	-	127	116	11	94	36.0	2.7	169
104	2	*7	17.8	7.8	7.8	2.47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
349	4	*13	19.9	1.9	1.9	4.44	-	.68	-	-	.002	.31	3.72	1.85	256	79	177	-	110	64	46	51	37.5	.9	98
Scioto	2	13	19.2	−.30	−.20	.490	-	.66	-	-	.003	.18	3.95	3.79	440	106	334	-	255	33	222	45	21.0	3.5	179
358	4	*13	19.9	1.9	1.9	4.93	-	.47	-	-	.003	.29	3.12	-	274	56	218	-	135	57	78	44	34.0	.9	106
461	2	-	20.1	3.6	3.3	7.21	-	.42	-	-	.002	.35	2.82	1.80	-	-	-	-	-	-	-	-	-	-	-
Licking	2	-	19.3	1.7	1.3	.960	-	.48	-	-	.006	.40	3.20	3.84	-	-	-	-	-	-	-	-	-	-	-
482	2	-	18.5	3.6	3.6	8.41	-	.73	-	-	.023	.30	2.35	4.08	-	-	-	-	-	-	-	-	-	-	-
Miami	1	-	18.3	2.1	2.2	.650	-	.84	-	-	.008	.45	3.70	-	-	-	-	-	-	-	-	-	-	-	-
598	4	-	19.6	2.9	2.8	10.4	-	.51	-	-	.017	.39	2.99	2.48	-	-	-	-	-	-	-	-	-	-	-
619	4	-	20.8	2.9	2.9	10.4	-	.68	-	-	.015	.46	4.00	3.55	-	-	-	-	-	-	-	-	-	-	-
904	2	*6	21.5	1.9	2.0	23.7	-	.64	-	-	.005	.20	3.65	2.04	314	97	217	-	130	26	104	Tr.	30.5	3.4	110
Cumberland	2	6	22.0	7.5	7.1	3.32	-	.91	-	-	.004	.32	4.92	2.28	281	60	221	-	78	6	72	Tr.	5.0	8.3	79
Tennessee	2	6	22.0	.4	.4	12.3	-	.56	-	-	.002	.22	4.58	1.80	313	73	240	-	92	26	66	44	20.0	8.3	70
933	2	*7	21.0	1.9	2.2	39.3	-	.61	-	-	.004	.15	3.95	1.51	301	84	217	-	108	19	89	Tr.	24.0	4.5	89

[2] Means for period October 1 to 15. Parts per million.

TABLE No. 50.—*Basic summary of chemical examinations at all sampling stations on the Ohio River and tributaries, by months, 1914 and 1915*—Continued

MONTHLY MEANS (Parts per million)—Continued.

OCTOBER, 1914

Sampling station	Total days samples taken: Sanitary	Total days samples taken: Mineral	Mean temperature. °C.	River stage: a	River stage: b	Mean discharge	Sanitary samples: Turbidity (silica scale)	Nitrogen as—: Total (Kjeldahl)	Nitrogen as—: Free ammonia	Nitrogen as—: Albuminoid ammonia	Nitrogen as—: Nitrites	Nitrogen as—: Nitrates	$KMnO_4$ oxygen consumed	Biochemical oxygen demand (total)	Mineral samples: Residue on evaporation (unfiltered): Total	Residue: Volatile	Residue: Fixed	Hardness ($CaCO_3$): By soap, total	Hardness: Soda reagent: Total	Hardness: Soda reagent: Incrustant	Alkalinity ($CaCO_3$)	Sulphate (SO_4)	Chlorine (Cl)	Total iron (Fe)	Total calcium ($CaCO_3$)
				Feet	*Feet*	*1,000 second-feet*																			
461	4	*10	18.1	5.9	5.8	12.7	-----	0.43	-----	-----	0.004	0.29	2.50	3.21	327	87	240	-----	122	53	69	46	29.5	4.7	91
Licking	4	20	16.4	3.2	3.0	3.60	-----	.87	-----	-----	.009	.26	3.46	5.10	411	71	340	-----	92	3	89	15	5.5	8.2	100
482	4	*22	18.1	5.9	5.8	16.9	-----	1.02	-----	-----	.016	.39	2.85	5.15	290	94	196	-----	120	51	69	69	28.5	4.0	102
Miami	2	14	15.0	2.5	2.2	1.24	-----	.78	-----	-----	.014	.40	4.50					-----							
598	9	*27	18.2	5.5	5.4	22.4	-----	.60	-----	-----	.018	.36	3.68	2.14	288	88	200	-----	128	45	83	42	32.5	2.2	104
619	8	*24	18.1	5.5	5.3	22.4	-----	.69	-----	-----	.017	.31	4.45	2.77	260	71	189	-----	130	48	82	45	32.0	1.0	102

NOVEMBER, 1914

Sampling station	Total days samples taken: Sanitary	Total days samples taken: Mineral	Mean temperature. °C.	River stage: a	River stage: b	Mean discharge	Sanitary samples: Turbidity (silica scale)	Nitrogen as—: Total (Kjeldahl)	Nitrogen as—: Free ammonia	Nitrogen as—: Albuminoid ammonia	Nitrogen as—: Nitrites	Nitrogen as—: Nitrates	$KMnO_4$ oxygen consumed	Biochemical oxygen demand (total)	Mineral samples: Residue on evaporation (unfiltered): Total	Residue: Volatile	Residue: Fixed	Hardness ($CaCO_3$): By soap, total	Hardness: Soda reagent: Total	Hardness: Soda reagent: Incrustant	Alkalinity ($CaCO_3$)	Sulphate (SO_4)	Chlorine (Cl)	Total iron (Fe)	Total calcium ($CaCO_3$)
461	*5	*13	9.1	4.8	4.9	11.4	-----	0.53	-----	-----	0.006	0.36	4.04	9.23	310	86	224	-----	142	73	69	43	44.0	0.5	112
Little Miami		13		5.9	5.9	.148	-----		-----	-----					316	80	236	-----	252	24	228	Tr.	12.0	.5	129
Licking	5	17	7.4	1.5	1.5	.228	-----	.59	-----	-----	.006	1.09	4.15	10.69	194	84	110	-----	125	17	108	Tr.	6.0	.8	115
482	*5	*20	6.7	4.8	4.9	11.8	-----	.90	-----	-----	.010	.35	4.67	10.15	287	65	222	-----	154	80	74	32	48.0	.7	111
Miami	3	10	6.2	2.2	2.2	.782	-----	.70	-----	-----	.025	.97	3.67		372	104	268	-----	290	44	246	36	13.0	1.0	193
598	*8	24	9.9	3.9	3.9	12.3	-----	.49	-----	-----	.014	.35	5.22	7.14	255	95	160	-----	160	72	88	65	34.9	.3	109
619	*8	*22	9.9	3.9	3.9	12.3	-----	.43	-----	-----	.014	.39	5.71	7.09	270	103	167	-----	165	65	100	64	31.0	.7	116

DECEMBER, 1914

461	*2	*18	4.0	18.0	16.9	81.1	----	0.80	----	----	0.008	0.15	11.65	7.58	387	65	322	----	123	80	43	39	34.0	11.7	87
Little Miami	----	10	----	7.6	7.8	1.03	----	----	----	----	----	----	----	----	424	98	326	----	----	----	209	Tr.	8.0	5.0	163
Licking	----	19	----	5.2	4.4	----	----	----	----	----	----	----	----	----	392	62	330	----	116	17	99	Tr.	7.0	11.3	105
482	*3	*17	2.7	18.0	18.6	88.2	----	.84	----	----	.009	.38	14.27	12.05	450	79	371	----	127	77	50	42	32.0	14.9	85
Miami	2	15	2.2	2.8	2.8	2.16	----	.60	----	----	.028	1.25	6.30	11.95	478	91	387	----	147	----	230	32	115.0	2.7	188
598	*8	*22	4.8	15.6	14.8	96.5	----	.80	----	----	.010	.54	9.56	8.25	415	59	356	----	218	161	57	30	28.0	9.5	87
619	*7	*18	3.9	15.6	14.2	96.5	----	.76	----	----	.009	.65	9.32	10.45	448	66	382	----	218	157	61	36	30.0	14.0	91

JANUARY, 1915

461	*7	*25	1.4	29.6	31.7	171.9	213	0.52	----	----	0.002	0.52	6.68	7.09	374	60	314	----	20	----	25	Tr.	9.5	10.6	67
Little Miami	2	7	----	8.8	9.2	2.61	215	.60	----	----	.006	1.90	6.00	----	486	76	410	----	127	29	98	24	4.5	12.1	67
Licking	3	24	----	6.7	7.2	9.26	298	.61	----	----	.007	2.88	5.80	6.02	531	63	468	----	96	21	75	Tr.	3.0	16.6	79
Mill Creek at 8th St. viaduct	3	----	2.0	----	----	----	70	1.66	----	----	.032	.87	13.80	----	----	----	----	----	----	----	----	----	----	----	----
482	*7	*24	1.6	29.6	31.9	183.8	251	.53	----	----	.003	.51	8.10	9.56	485	66	419	----	59	29	30	32	9.0	15.2	45
Miami	5	21	.7	4.3	4.2	3.89	145	.74	----	----	.014	1.64	6.70	10.02	556	114	442	----	232	49	183	Tr.	5.0	9.0	160
Kentucky	----	8	----	10.2	10.1	13.2	----	----	----	----	----	----	----	----	488	68	420	----	69	12	57	Tr.	2.5	11.1	34
598	*8	*24	1.6	29.1	29.7	221.6	344	.75	----	----	.003	.56	9.00	9.18	519	71	448	----	69	31	38	Tr.	7.5	17.5	50
619	*8	*24	1.7	29.1	29.7	221.6	364	.89	----	----	.005	.63	8.80	9.80	520	67	453	----	69	23	46	Tr.	4.0	17.5	53

FEBRUARY, 1915

461	*7	*21	2.9	35.2	34.5	223.0	204	0.53	----	----	0.007	0.73	6.30	5.30	299	46	253	----	64	35	29	26	8.0	9.2	49
Little Miami	5	10	3.8	11.8	11.6	11.5	149	.75	----	----	.011	2.25	6.40	5.34	356	71	285	----	186	32	154	Tr.	5.5	4.7	140
Licking	4	21	3.8	6.8	5.9	10.6	135	.56	----	----	.007	1.68	5.60	3.11	336	52	284	----	106	25	81	Tr.	4.0	10.0	94
Mill Creek at 8th St. viaduct	4	----	5.5	----	----	----	136	3.47	----	----	.132	1.53	16.7	----	----	----	----	----	----	----	----	----	----	----	----
482	*5	*19	3.0	35.2	35.4	245.1	179	.66	----	----	.010	.87	6.30	7.19	331	45	286	----	66	37	29	30	7.0	9.2	53
Miami	4	17	3.6	6.4	6.5	17.8	158	.76	----	----	.019	3.00	5.30	7.67	492	119	373	----	214	49	165	22	5.5	3.0	89
543	----	*8	----	30.9	30.9	266.8	----	----	----	----	----	----	----	----	341	85	256	----	72	35	37	28	8.5	3.5	74
Kentucky	----	8	----	10.2	10.1	13.2	----	----	----	----	----	----	----	----	454	74	380	----	91	20	71	Tr.	3.5	7.4	111
598	*7	*23	3.4	36.4	37.2	309.0	200	.78	----	----	.006	.90	8.60	7.81	468	67	401	----	74	31	43	33	6.5	5.6	61
619	*8	*22	3.4	36.4	36.5	309.1	241	.85	----	----	.008	.83	10.10	6.99	508	68	440	----	72	28	44	14	6.0	----	57

TABLE No. 50.—*Basic summary of chemical examinations at all sampling stations on the Ohio River and tributaries, by months, 1914 and 1915*—Continued

MONTHLY MEANS (Parts per million)—Continued

MARCH, 1915

Sampling station	Total days samples taken: Sanitary	Total days samples taken: Mineral	Mean temperature, °C.	River stage: a	River stage: b	Mean discharge	Sanitary samples: Turbidity (silica scale)	Nitrogen as—Total (Kjeldahl)	Nitrogen as—Free ammonia	Nitrogen as—Albuminoid ammonia	Nitrogen as—Nitrites	Nitrogen as—Nitrates	$KMnO_4$ oxygen consumed	Biochemical oxygen demand (total)	Mineral samples: Residue on evaporation (unfiltered): Total	Residue: Volatile	Residue: Fixed	Hardness ($CaCO_3$): By soap, total	Hardness: Soda reagent: Total	Hardness: Soda reagent: Incrustant	Alkalinity ($CaCO_3$)	Sulphate (SO_4)	Chlorine (Cl)	Total iron (Fe)	Total calcium ($CaCO_3$)
				Feet	Feet	1,000 second-feet																			
461	*8	*25	4.0	17.9	17.6	79.4	79	0.53	-----	-----	0.004	0.43	3.84	4.76	233	55	178	-----	74	40	34	32	11.0	7.9	55
Little Miami	5	14	4.4	7.2	6.9	.633	29	.42	-----	-----	.007	1.62	2.90	4.95	344	115	229	-----	241	39	202	32	6.5	4.0	168
Licking	5	27	4.4	4.1	3.9	4.21	87	.50	-----	-----	.003	1.18	4.20	3.88	300	57	243	-----	103	22	81	61	7.3	9.0	89
Mill Creek at 8th St. viaduct	4	-----	7.0	-----	-----	-----	156	6.78	-----	-----	.078	.44	36.6	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
482	*9	*27	4.5	17.9	18.2	84.2	92	.49	-----	-----	.002	.42	6.10	6.26	268	58	210	-----	76	40	36	31	11.0	13.6	59
Miami	4	22	5.1	4.1	4.1	3.03	33	.53	-----	-----	.010	1.25	5.70	5.92	417	100	317	-----	267	42	225	42	14.0	3.9	209
543	-----	*8	-----	16.7	17.1	88.5	-----	-----	-----	-----	-----	-----	-----	-----	274	46	228	-----	83	37	46	65	18.5	9.7	61
Kentucky	-----	8	-----	9.8	10.4	12.3	-----	-----	-----	-----	-----	-----	-----	-----	454	74	380	-----	91	20	71	Tr.	3.5	7.4	111
598	*9	*27	4.8	16.4	16.8	98.8	111	.59	-----	-----	.004	.47	7.90	6.85	252	43	209	-----	76	29	47	59	19.5	8.0	55
619	*9	*27	4.8	16.4	16.8	98.8	118	.74	-----	-----	.003	.49	7.60	5.58	338	73	265	-----	84	34	50	58	20.0	17.5	62

APRIL, 1915

Sampling station	Total days samples taken: Sanitary	Total days samples taken: Mineral	Mean temperature, °C.	River stage: a	River stage: b	Mean discharge	Sanitary samples: Turbidity (silica scale)	Nitrogen as—Total (Kjeldahl)	Nitrogen as—Free ammonia	Nitrogen as—Albuminoid ammonia	Nitrogen as—Nitrites	Nitrogen as—Nitrates	$KMnO_4$ oxygen consumed	Biochemical oxygen demand (total)	Mineral samples: Residue on evaporation (unfiltered): Total	Residue: Volatile	Residue: Fixed	Hardness ($CaCO_3$): By soap, total	Hardness: Soda reagent: Total	Hardness: Soda reagent: Incrustant	Alkalinity ($CaCO_3$)	Sulphate (SO_4)	Chlorine (Cl)	Total iron (Fe)	Total calcium ($CaCO_3$)
461	*9	*26	12.4	11.8	11.4	40.0	28	0.47	-----	-----	0.004	0.26	2.46	2.82	172	51	121	-----	84	44	40	26	19.0	1.0	61
Little Miami	4	12	17.3	6.4	6.4	.280	21	.63	-----	-----	.009	.78	4.00	3.30	316	96	220	-----	246	30	216	30	10.0	.5	159
Licking	4	26	17.3	2.5	2.4	1.36	25	.49	-----	-----	.001	.19	2.60	2.92	242	44	198	-----	99	19	80	34	7.0	5.4	78
Mill Creek at 8th St. viaduct	5	-----	18.1	-----	-----	-----	150	10.86	-----	-----	.035	.02	50.6	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
482	*9	*26	12.2	11.8	11.6	41.6	26	.52	-----	-----	.005	.30	3.10	4.76	178	52	126	-----	90	45	45	34	19.5	1.0	66
Miami	5	22	14.6	3.7	3.7	1.90	46	.80	-----	-----	.019	1.25	4.40	6.80	450	147	303	-----	279	44	235	25	11.5	5.0	178
543	-----	*9	-----	12.0	12.0	44.2	-----	-----	-----	-----	-----	-----	-----	-----	210	67	143	-----	90	41	49	25	15.5	1.5	69
Kentucky	-----	9	-----	7.3	7.3	2.74	-----	-----	-----	-----	-----	-----	-----	-----	128	36	92	-----	71	24	47	Tr.	4.0	1.5	37
598	*9	*26	12.8	10.0	10.1	48.3	12	.53	-----	-----	.008	.29	4.40	3.84	206	64	142	-----	92	42	50	31	15.0	1.0	69
619	*8	*24	12.3	10.0	10.3	48.3	18	.59	-----	-----	.006	.33	4.50	5.29	128	36	92	-----	71	24	47	Tr.	4.0	1.5	37

MAY, 1915

461	*8	*25	18.6	14.7	13.0	50.9	126	1.01	-----	-----	0.004	0.21	5.04	-----	514	78	436	-----	91	43	48	39	17.0	11.3	65
Little Miami	4	12	18.1	6.6	6.3	.607	1,136	4.39	-----	-----	.024	.39	20.90	-----	1,042	182	860	-----	236	26	210	Tr.	9.0	21.8	141
Licking	4	25	18.1	4.2	4.1	4.50	4,239	7.18	-----	-----	.009	1.44	27.90	-----	1,720	166	1,554	-----	85	-----	96	24	4.0	35.0	92
Mill Creek at 8th St. viaduct	4	-----	18.2	-----	-----	-----	168	10.00	-----	-----	.067	.44	22.00	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
482	*8	*25	18.7	14.7	12.7	56.0	559	1.50	-----	-----	.004	.32	11.80	-----	557	79	478	-----	89	38	51	38	17.0	21.8	66
Miami	4	21	17.3	3.9	3.8	2.84	221	1.52	-----	-----	.015	1.00	7.70	-----	497	132	365	-----	256	40	216	37	9.0	5.4	164
543	-----	*8	-----	13.2	12.5	59.7	-----	-----	-----	-----	-----	-----	-----	-----	413	80	333	-----	94	40	54	41	14.5	10.6	66
Kentucky	-----	8	-----	7.5	7.3	3.76	-----	-----	-----	-----	-----	-----	-----	-----	200	55	145	-----	98	18	80	Tr.	4.0	1.5	77
598	*8	*25	19.2	11.5	10.6	63.8	79	.98	-----	-----	.007	.28	6.30	-----	378	62	316	-----	95	36	59	35	15.5	7.3	67

JUNE, 1915

461	*7	*26	22.1	16.7	16.8	69.5	394	1.31	-----	-----	0.003	0.38	9.50	-----	427	71	356	-----	85	37	48	24	14.5	9.0	62
Little Miami	1	-----	18.5	7.8	9.8	1.31	240	1.03	-----	-----	.030	.35	8.00	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Licking	1	26	18.5	4.0	4.6	3.96	600	1.75	-----	-----	.012	1.50	9.10	-----	467	126	341	-----	114	4	110	Tr.	5.0	28.0	94
Mill Creek at 8th St. viaduct	3	-----	20.7	-----	-----	-----	103	5.35	-----	-----	.039	.83	19.8	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
482	*8	*26	22.5	16.7	16.4	74.8	379	1.33	-----	-----	.004	.39	9.10	-----	577	78	499	-----	94	38	56	23	16.0	20.0	67
Miami	4	21	21.6	4.4	4.4	4.23	241	1.48	-----	-----	.016	1.27	8.50	-----	814	137	677	-----	251	43	208	23	8.5	14.0	166
543	-----	*9	-----	15.5	16.1	80.2	-----	-----	-----	-----	-----	-----	-----	-----	366	74	292	-----	86	28	58	20	14.5	18.0	67
Kentucky	-----	9	-----	8.1	8.2	5.42	-----	-----	-----	-----	-----	-----	-----	-----	530	81	449	-----	72	-----	81	Tr.	3.0	32.0	71
598	*9	*26	22.6	15.8	16.6	94.1	323	1.20	-----	-----	.004	.46	9.30	-----	290	67	223	-----	85	18	67	17	14.0	11.2	71

JULY, 1915

461	*8	*26	24.8	17.3	18.1	66.3	490	3.50	-----	-----	0.000	0.53	7.10	-----	640	79	561	-----	80	36	56	21	19.0	6.0	73
Licking	-----	26	-----	5.4	5.0	-----	-----	-----	-----	-----	-----	-----	-----	-----	994	101	893	-----	80	0	80	Tr.	6.0	9.0	76
Mill Creek at 8th St. viaduct	4	-----	23.8	-----	-----	-----	667	5.80	-----	-----	.065	0.00	29.4	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
482	*8	*26	25.1	17.3	16.5	75.2	427	2.94	-----	-----	.001	.20	9.10	-----	754	96	658	-----	90	30	60	30	18.0	6.0	75
Miami	5	22	23.5	5.6	6.0	11.3	692	4.20	-----	-----	.024	1.18	15.00	-----	1,272	144	1,128	-----	202	22	180	20	9.0	9.0	146
543	-----	*9	-----	16.4	16.3	87.8	-----	-----	-----	-----	-----	-----	-----	-----	644	92	552	-----	101	32	69	20	16.0	35.0	80
Kentucky	-----	9	-----	9.3	8.8	9.45	-----	-----	-----	-----	-----	-----	-----	-----	1,037	105	932	-----	79	-----	105	Tr.	5.0	28.0	80
598	*9	*26	25.6	16.8	16.5	102.5	224	2.50	-----	-----	.022	.26	8.60	-----	475	80	395	-----	98	18	80	18	16.0	18.4	62

TABLE No. 50.—*Basic summary of chemical examinations at all sampling stations on the Ohio River and tributaries, by months, 1914 and 1915*—Continued

MONTHLY MEANS (Parts per million)—Continued

AUGUST, 1915

Sampling station	Total days samples taken: Sanitary	Total days samples taken: Mineral	Mean temperature. °C.	River stage: a	River stage: b	Mean discharge	Sanitary samples: Turbidity (silica scale)	Nitrogen as—: Total (Kjeldahl)	Nitrogen as—: Free ammonia	Nitrogen as—: Albuminoid ammonia	Nitrogen as—: Nitrites	Nitrogen as—: Nitrates	KMnO₄ oxygen consumed	Biochemical oxygen demand (total)	Mineral samples: Residue on evaporation (unfiltered): Total	Residue: Volatile	Residue: Fixed	Hardness (CaCO₃): By soap, total	Hardness: Soda reagent: Total	Hardness: Soda reagent: Incrustant	Alkalinity (CaCO₃)	Sulphate (SO₄)	Chlorine (Cl)	Total iron (Fe)	Total calcium (CaCO₃)
				Feet	*Feet*	*1,000 second-feet*																			
461	*9	*26	24.1	13.9	13.4	50.2	167	2.10	-----	-----	0.000	0.21	8.60	-----	316	67	249	-----	99	40	59	40	19.0	10.0	76
Licking	-----	26	-----	3.2	3.4	-----	-----	-----	-----	-----	-----	-----	-----	-----	822	88	734	-----	102	11	91	Tr.	5.0	40.0	85
Mill Creek at 8th St. viaduct	4	-----	20.6	-----	-----	-----	124	5.40	-----	-----	.024	.11	12.6	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
482	*9	*25	27.2	13.9	13.7	54.8	300	2.07	-----	-----	.001	.12	10.10	-----	469	80	389	-----	102	37	65	35	20.5	20.0	80
Miami	4	22	20.5	4.7	4.5	5.44	243	2.25	-----	-----	.004	.55	10.70	-----	904	118	786	-----	227	28	199	24	8.5	30.0	154
543	-----	*9	-----	13.3	13.3	61.1	-----	-----	-----	-----	-----	-----	-----	-----	451	76	375	-----	116	38	78	33	18.0	18.0	88
Kentucky	-----	9	-----	7.8	7.7	4.28	-----	-----	-----	-----	-----	-----	-----	-----	464	61	403	-----	88	9	79	Tr.	6.0	20.0	75
598	*9	*26	24.2	12.4	12.2	66.4	187	1.91	-----	-----	.003	.18	8.70	-----	327	72	255	-----	119	37	82	30	17.0	8.0	87

SEPTEMBER, 1915

Sampling station	Sanitary	Mineral	Mean temperature. °C.	a	b	Mean discharge	Turbidity (silica scale)	Total (Kjeldahl)	Free ammonia	Albuminoid ammonia	Nitrites	Nitrates	KMnO₄ oxygen consumed	Biochemical oxygen demand (total)	Total	Volatile	Fixed	By soap, total	Total	Incrustant	Alkalinity (CaCO₃)	Sulphate (SO₄)	Chlorine (Cl)	Total iron (Fe)	Total calcium (CaCO₃)
461	*8	*25	22.4	13.8	13.0	48.2	140	0.88	-----	-----	0.002	0.20	4.70	-----	324	60	264	-----	102	37	65	22	21.0	13.2	77
Licking	-----	25	-----	2.3	2.3	-----	-----	-----	-----	-----	-----	-----	-----	-----	385	52	333	-----	145	6	139	Tr.	6.0	16.8	129
Mill Creek at 8th St. viaduct	5	-----	19.4	-----	-----	-----	52	1.13	-----	-----	.100	.10	21.3	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
482	*8	*25	22.6	13.8	12.5	52.1	156	.83	-----	-----	.012	.21	5.70	-----	344	66	278	-----	109	36	73	20	21.0	13.2	81
Miami	4	20	21.1	4.8	4.8	6.40	162	1.07	-----	-----	.006	1.34	5.20	-----	468	120	348	-----	250	30	220	20	8.5	12.0	166
543	-----	*8	-----	12.9	13.3	59.3	-----	-----	-----	-----	-----	-----	-----	-----	435	100	335	-----	120	20	100	18	16.5	16.0	93
Kentucky	-----	8	-----	7.1	7.2	2.26	-----	-----	-----	-----	-----	-----	-----	-----	410	92	318	-----	112	12	100	27	9.0	18.0	93
598	*9	*25	22.5	11.7	11.9	61.2	151	.82	-----	-----	.005	.26	5.30	-----	312	94	218	-----	112	24	88	20	16.5	11.6	90

OCTOBER, 1915

461	*9	*26	16.2	16.1	15.6	66.2	146	0.79			0.003	0.14	7.50		374	114	260		84	34	50	22	18.0		64
Licking		26		3.3	3.1										320	106	214		95	7	88	Tr.	11.0		81
Mill Creek at 8th St. viaduct	4		15.6				200	1.11			.000	.00	25.9												
482	*8	*26	16.6	16.1	16.4	70.4	167	.91			.005	.22	6.50		433	119	314		94	40	54	20	17.5		66
Miami	5	24	15.2	4.4	4.5	4.63	85	.81			.004	.88	5.70		547	179	368		262	38	224	23	2.5		166
543		*8		14.7		76.1									321	72	249		99	31	68	23	17.5		76
Kentucky		8		8.1	8.1	5.30									294	60	234		72	3	69	Tr.	4.5		64
598	*8	*26	16.8	14.3	13.4	85.1	165	.82			.004	.30	7.20		340	110	230		102	34	68	23	16.0		76

NOVEMBER, 1915

461	*9	*25	9.7	15.9	13.2	53.2	83	0.98			0.001	0.27	5.70		262	67	195		106	53	53	52	21.5	6.0	73
Licking		25		3.8	4.0										333	92	241		104	14	90	19	9.0	10.0	84
Mill Creek at 8th St. viaduct	4		11.2				65	6.50			.000	.00	26.0												
482	*9	*24	10.2	15.9	12.9	58.6	91	1.11			.000	.23	5.60		288	82	206		104	49	55	49	21.5	7.6	78
Miami	4	24	9.1	4.1	4.4	3.41	74	1.29			.006	1.05	5.70		381	129	252		297	57	240	47	9.0	2.0	185
543		*8				62.9									382	69	313		124	46	78	42	20.5	7.4	91
Kentucky		8		8.3	8.4	7.06									421	70	351		102	13	89	Tr.	4.0	10.0	86
598	*8	*25	11.6	12.6	11.4	72.5	123	1.00			.002	.33	7.60		333	75	258		115	43	72	40	20.0	4.4	87

DECEMBER, 1915

461	*6	*24	2.9	24.2	22.9	125.0	159	1.02			0.001	0.32	7.00		333				76	36	40	32	16.0	8.0	54
Licking		25		9.4	9.4										446	65	381		104	17	87	18	4.5	14.0	82
Mill Creek at 8th St. viaduct	5		5.1				133	5.90			.030	.51	27.4												
482	*9	*25	3.1	24.2	24.1	149.0	189	1.17			.001	.33	8.30		376	56	320		79	30	49	30	14.0	8.8	61
Miami	4	25	2.6	4.8	5.1	6.58	78	1.09			.003	1.28	8.00		477	123	354		242	38	204	39	8.0	8.8	156
543		*9				157.9									335	64	271		89	31	58	27	14.5	11.2	65
Kentucky		9		14.9	14.4	34.0									460	68	392		75	11	64	18	6.0	13.2	62
598	*9	*26	3.2	25.4	25.1	201.0	280	1.14			.002	.39	10.60		435	73	362		86	29	57	30	14.5	14.0	66

TABLE No. 51.—*Basic summary of all dissolved oxygen determinations at sampling stations on the Ohio River and tributaries, by months, May, 1914, to April, 1915, inclusive*

MAY, 1914

Station	Mean water tempera-ture °C.	Mean time of flow, days from—		Initial dissolved oxygen			Loss during 24 hours incuba-tion at 20° C. (p. p. m.)	Total oxygen demand	
		Pitts-burgh	Sta-tion next above	Parts per million	Per cent satura-tion	Satura-tion deficit (p. p. m.)		Parts per million	Quanity units (p. p. m. × thou-sand sec-ond-feet)
Allegheny-7	19. 9	--------	--------	9. 00	98. 0	. 19	0. 45	2. 18	71. 5
Monongahela-12	23. 5	--------	--------	7. 21	83. 0	1. 39	. 36	1. 75	16. 5
Ohio No. 3	15. 8	0. 09	0. 09	9. 10	91. 1	. 89	. 99	4. 80	202. 5
Ohio No. 11	16. 0	. 30	. 21	9. 32	93. 8	. 63	1. 05	5. 10	215. 0
Ohio No. 19	15. 8	. 48	. 18	9. 27	92. 8	. 72	. 94	4. 56	192. 3
Ohio No. 23	16. 0	. 56	. 08	9. 10	91. 5	. 85	. 89	4. 32	182. 5
Beaver	17. 7	. 60	. 04	9. 29	96. 8	. 31	1. 14	5. 53	65. 3
Ohio No. 29	14. 3	. 66	. 06	9. 53	92. 5	. 77	1. 41	6. 84	340. 0
Ohio No. 65	16. 6	1. 18	. 52	8. 60	87. 6	1. 22	. 97	4. 70	261. 6
Ohio No. 77	16. 8	1. 38	. 20	8. 80	90. 0	. 98	1. 07	5. 20	289. 5
Ohio No. 88	16. 8	1. 56	. 18	8. 89	90. 9	. 89	1. 47	7. 13	397. 0
Ohio No. 97	16. 3	1. 71	. 15	8. 71	88. 1	1. 18	1. 36	6. 60	367. 0
Ohio No. 104	16. 4	1. 86	. 15	8. 37	84. 9	1. 50	1. 01	5. 05	281. 0
Ohio No. 349	17. 0	5. 89	4. 03	8. 43	86. 6	1. 31	. 25	1. 21	122. 2
Scioto	18. 6	6. 00	. 11	8. 26	87. 0	1. 17	. 60	2. 92	20. 3
Ohio No. 461	17. 6	7. 65	1. 65	8. 20	85. 8	1. 42	. 46	2. 24	269. 0
Little Miami	18. 8	7. 67	. 02	8. 41	89. 7	. 98	. 79	3. 84	7. 0
Licking	19. 4	7. 77	. 10	8. 60	92. 6	. 68	1. 10	5. 34	21. 4
Ohio No. 475	17. 1	7. 87	. 10	8. 18	84. 2	1. 54	. 79	3. 84	483. 0
Ohio No. 482	17. 1	8. 00	. 13	8. 17	84. 2	1. 55	. 85	4. 13	520. 0
Ohio No. 488	17. 0	8. 11	. 10	8. 14	83. 5	1. 60	. 64	3. 11	392. 0
Miami	17. 5	8. 12	. 02	8. 63	89. 5	1. 01	. 98	4. 76	21. 0
Ohio No. 492	16. 9	8. 16	. 04	8. 09	82. 9	1. 67	. 78	3. 79	494. 0
Ohio No. 598	17. 6	10. 14	1. 98	8. 01	83. 3	1. 61	. 70	3. 40	499. 0
Ohio No. 611	18. 0	10. 42	. 28	7. 90	82. 8	1. 64	. 73	3. 55	521. 0

JUNE, 1914

Station	Mean water tempera-ture °C.	Pitts-burgh	Sta-tion next above	Parts per million	Per cent satura-tion	Satura-tion deficit (p. p. m.)	Loss during 24 hours incuba-tion at 20° C. (p. p. m.)	Parts per million	Quanity units (p. p. m. × thou-sand sec-ond-feet)
Allegheny-7	23. 0	--------	--------	7. 59	87. 5	1. 09	0. 31	1. 51	9. 9
Monongahela-12	24. 0	--------	--------	6. 41	75. 2	2. 09	. 27	1. 31	3. 7
Ohio No. 3	24. 0	0. 38	. 38	5. 40	63. 3	3. 13	. 34	1. 65	15. 5
Ohio No. 11	25. 0	1. 45	1. 07	7. 29	87. 0	1. 09	. 43	2. 08	19. 5
Ohio No. 19	24. 0	2. 22	. 77	7. 39	86. 6	1. 14	. 38	1. 85	17. 4
Ohio No. 23	23. 4	2. 54	. 32	7. 29	84. 7	1. 33	. 32	1. 55	14. 5
Beaver	23. 4	2. 70	. 16	7. 70	89. 3	. 92	. 49	2. 38	2. 0
Ohio No. 29	----------	2. 96	. 26	8. 01	93. 0	. 66	. 18	. 87	8. 8
Ohio No. 65	22. 7	4. 44	1. 48	7. 79	89. 4	. 93	. 52	2. 52	26. 0
Ohio No. 77	23. 7	5. 46	1. 02	8. 11	94. 8	. 46	. 57	2. 77	28. 5
Ohio No. 88	23. 7	6. 11	. 65	8. 18	95. 6	. 39	. 75	3. 64	37. 5
Ohio No. 97	22. 6	6. 69	. 58	7. 71	88. 2	1. 03	. 57	2. 77	28. 5
Ohio No. 104	23. 3	7. 23	. 54	7. 67	88. 9	. 96	. 71	3. 45	35. 5
Ohio No. 349	25. 5	17. 32	10. 09	7. 42	89. 4	. 88	. 42	2. 04	36. 5
Scioto	24. 5	17. 52	. 20	7. 76	90. 6	. 69	1. 03	5. 00	5. 0
Ohio No. 461	26. 2	20. 24	2. 72	7. 88	96. 3	. 21	. 50	2. 43	48. 1
Licking	27. 6	20. 54	. 30	6. 88	86. 2	1. 10	. 98	4. 76	4. 9
Ohio No. 475	26. 2	20. 91	. 37	6. 35	77. 5	1. 84	. 90	4. 37	91. 6
Ohio No. 482	25. 8	21. 39	. 48	6. 79	82. 3	1. 46	. 91	4. 42	92. 8
Ohio No. 488	25. 6	21. 64	. 25	6. 45	77. 9	1. 83	. 74	3. 60	75. 5
Miami	25. 6	21. 69	. 05	7. 90	95. 4	. 38	1. 50	7. 28	9. 0
Ohio No. 492	25. 0	21. 77	. 08	6. 48	77. 3	1. 90	. 90	4. 37	98. 0
Ohio No. 598	25. 3	27. 83	6. 06	7. 51	90. 2	. 82	. 95	4. 61	132. 8
Ohio No. 611	25. 9	28. 78	. 95	7. 38	89. 6	. 86	. 82	3. 98	114. 5
Ohio No. 904	26. 9	41. 62	13. 79	7. 24	89. 6	. 84	. 40	1. 94	90. 4
Cumberland	29. 4	41. 96	. 34	5. 56	88. 3	2. 15	. 00	. 00	0. 0
Ohio No. 920	26. 9	42. 34	. 38	7. 44	92. 1	. 64	. 35	1. 70	86. 8
Tennessee	29. 6	42. 40	. 06	6. 56	85. 3	1. 13	. 26	1. 26	21. 5
Ohio No. 933	28. 0	42. 95	. 55	7. 20	90. 9	. 72	. 77	3. 74	255. 0

TABLE No. 51.—*Basic summary of all dissolved oxygen determinations at sampling stations on the Ohio River and tributaries, by months, May, 1914, to April, 1915, inclusive*—Continued

JULY, 1914

Station	Mean water temperature °C.	Mean time of flow, days from—		Initial dissolved oxygen			Loss during 4 hours incubation at 20° C. (p. p. m.)	Total oxygen demand	
		Pittsburgh	Station next above	Parts per million	Per cent saturation	Saturation deficit (p. p. m.)		Parts per million	Quantity units (p. p. m. × thousand second-feet)
Allegheny-7	24.5			7.36	87.1	1.02	0.33	1.60	5.5
Monongahela-12	25.0			6.58	78.6	1.78	.43	2.09	4.0
Ohio No. 3	25.1	0.68	0.68	4.36	52.1	4.00	.44	2.14	11.5
Ohio No. 11	24.0	2.49	1.81	7.21	84.5	1.32	.41	1.99	10.7
Ohio No. 19	24.2	3.85	1.36	7.46	87.8	1.04	.44	2.14	11.5
Ohio No. 23	24.5	4.45	.60	7.21	85.3	1.24	.48	2.33	12.6
Beaver	23.8	4.74	.29	7.42	86.7	1.14	.64	3.11	1.4
Ohio No. 65	24.6	7.45	2.71	7.50	88.9	.94	.24	1.16	7.7
Ohio No. 77	25.0	9.09	1.73	7.84	93.5	.54	.39	1.90	12.6
Ohio No. 88	25.0	10.20	1.01	7.86	93.8	.52	.49	2.38	15.8
Ohio No. 97	24.8	11.20	1.00	7.74	92.1	.67	.33	1.60	11.6
Ohio No. 104	24.8	12.11	.91	7.49	89.0	.92	.31	1.51	10.0
Ohio No. 349	26.7	24.90	12.79	6.83	84.2	1.28	.38	1.85	30.3
Scioto	25.6	25.10	.20	7.57	89.6	.71	.90	4.37	3.2
Ohio No. 461	27.1	27.86	2.76	7.70	95.6	.35	.40	1.94	36.3
Licking	29.3	28.21	.35	6.63	85.7	1.10	.83	4.03	0.4
Ohio No. 475	27.3	28.64	.43	6.00	74.9	2.02	.81	3.94	74.8
Ohio No. 482	26.8	29.20	.56	6.76	83.5	1.34	.81	3.93	74.6
Ohio No. 488	27.2	29.46	.26	6.62	82.3	1.42	.68	3.30	62.7
Ohio No. 492	26.5	29.60	.14	6.43	77.8	.71	.66	3.20	64.0
Ohio No. 598	27.0	36.86	7.26	7.70	95.5	.37	1.01	4.90	113.0
Ohio No. 611	27.2	38.06	1.20	7.45	92.6	.59	.84	4.08	94.4
Ohio No. 619	27.2	38.38	.32	7.06	87.8	.98	.98	4.76	109.8
Ohio No. 904	28.3	53.19	14.81	7.51	95.5	.36	.32	1.55	47.7
Cumberland	28.9	53.64	.45	6.28	80.8	1.50	.26	1.26	10.1
Ohio No. 920	28.9	54.05	.41	7.34	94.4	.44	.21	1.04	40.3
Tennessee	29.7	54.11	.06	6.47	84.3	1.20	.18	.87	16.7
Ohio No. 933	29.0	54.69	.58	6.90	88.8	.87	.28	1.36	78.8

AUGUST, 1914

Station	Mean water temperature °C.	Mean time of flow, days from—		Initial dissolved oxygen			Loss during 4 hours incubation at 20° C. (p. p. m.)	Total oxygen demand	
		Pittsburgh	Station next above	Parts per million	Per cent saturation	Saturation deficit (p. p. m.)		Parts per million	Quantity units (p. p. m. × thousand second-feet)
Allegheny-7	23.0			7.16	82.4	1.52	0.39	1.89	3.1
Monongahela-12	24.8			6.40	76.0	2.01	.71	3.45	7.1
Ohio No. 3	25.0	1.00	1.00	2.85	34.0	5.53	.61	2.96	11.0
Ohio No. 11	24.5	3.73	2.73	6.50	76.9	1.95	.51	2.48	9.2
Ohio No. 19	24.4	5.71	1.98	6.87	81.1	1.60	.52	2.52	9.4
Ohio No. 23	24.0	6.59	.88	6.65	77.9	1.88	.38	1.85	6.9
Beaver	23.0	7.01	.42	7.40	85.2	1.28	.52	2.52	0.9
Ohio No. 65	24.2	11.49	4.48	7.75	91.2	.75	.28	1.36	6.3
Ohio No. 77	24.6	13.81	2.47	7.95	94.2	.49	.12	.58	2.7
Ohio No. 88	24.4	15.47	1.51	7.76	91.7	.71	.50	2.43	11.3
Ohio No. 97	24.2	16.92	1.45	7.90	93.0	.50	.55	2.67	12.4
Ohio No. 104	23.9	18.26	1.34	7.59	88.9	.95	.35	1.70	7.9
Ohio No. 349	25.7	34.88	16.62	7.09	85.8	1.18	.37	1.80	21.2
Scioto	24.8	35.12	.24	7.37	87.3		.83	4.03	3.9
Ohio No. 461	26.4	38.34	3.22	7.27	89.1	.89	.49	2.38	33.0
Licking	27.2	38.64	.30	6.58	81.8	1.46	1.01	4.90	3.6
Ohio No. 475	26.3	39.32	.68	4.97	60.8	3.20	.79	3.84	58.4
Ohio No. 482	25.8	40.01	.69	6.39	77.5	1.86	.74	3.59	53.0
Ohio No. 488	25.9	40.30	.29	6.24	75.8	2.00	.65	3.15	47.9
Ohio No. 492	25.0	40.45	.15	6.23	74.3	2.15	.66	3.20	52.8
Ohio No. 598	26.0	48.98	8.67	7.81	96.6	.41	.33	1.60	29.3
Ohio No. 611	27.0	50.42	1.44	7.79	95.0	.28	.38	1.85	33.8
Ohio No. 619	27.1	50.80	.38	7.33	91.1	.72	.60	2.91	53.2
Ohio No. 904	27.5	67.54	16.74	7.18	89.9	.81	.16	.78	20.6
Cumberland	28.0	67.88	.34	6.28	79.3	1.64	.18	.87	6.0
Ohio No. 920	27.9	68.37	.49	7.78	98.2	.15	.40	1.94	64.5
Tennessee	28.4	68.43	.06	6.95	88.4	.91	.24	1.17	19.5
Ohio No. 933	27.9	69.00	.57	7.09	89.4	.84	.30	1.46	73.0

TABLE No. 51.—*Basic summary of all dissolved oxygen determinations at sampling stations on the Ohio River and tributaries, by months, May, 1914, to April, 1915, inclusive*—Continued

SEPTEMBER, 1914

Station	Mean water tempera-ture °C.	Mean time of flow, days from—		Initial dissolved oxygen			Loss during 24 hours incuba-tion at 20° C. (p. p. m.)	Total oxygen demand	
		Pitts-burgh	Sta-tion next above	Parts per million	Per cent satura-tion	Satura-tion deficit (p. p. m.)		Parts per million	Quantity units (p. p. m. ×thou-sand sec-ond-feet)
Allegheny-7	19.0			8.25	88.2	1.10	0.46	2.24	5.0
Monongahela-12	21.0			6.54	71.3	2.45	.55	2.67	3.0
Ohio No. 3	21.0	1.05	1.05	2.71	30.2	6.28	.59	2.86	9.6
Ohio No. 11	20.5	4.11	3.06	6.59	72.6	2.49	.44	2.14	7.2
Ohio No. 19	20.5	6.41	2.30	7.09	78.0	1.99	.54	2.62	8.8
Ohio No. 23	20.3	7.35	.94	5.33	58.7	3.77	.08	.39	1.3
Beaver	19.0	7.82	.47	7.73	82.7	1.38	.27	1.31	.5
Ohio No. 65	19.8	13.49	5.67	8.45	91.8	.76	.23	1.12	5.0
Ohio No. 77	20.3	15.88	2.54	8.68	95.2	.44	.32	1.55	7.0
Ohio No. 88	20.4	17.54	1.51	8.77	96.3	.33	.58	2.82	12.7
Ohio No. 97	20.4	19.02	1.48	8.72	95.9	.38	.56	2.72	12.2
Ohio No. 104	20.3	20.36	1.34	8.32	91.3	.80	.53	2.58	11.6
Ohio No. 349	22.3	36.12	15.76	7.74	88.0	1.04	.30	1.46	20.0
Scioto	21.1	36.34	.22	8.29	92.3	.68	.79	3.84	3.1
Ohio No. 461	22.1	39.27	2.93	7.64	86.8	1.17	.44	2.14	36.6
Licking	22.5	39.65	.38	7.43	84.9	1.32	.73	3.55	.8
Ohio No. 475	22.6	40.11	.46	5.87	67.1	2.87	.89	4.32	75.5
Ohio No. 482	22.5	40.72	.61	6.91	79.0	1.84	.74	3.59	62.8
Ohio No. 488	22.3	40.99	.27	6.76	77.0	2.02	.62	3.01	52.7
Ohio No. 492	22.0	41.14	.15	6.82	77.2	1.01	.64	3.11	56.9
Ohio No. 598	22.9	48.86	7.72	8.43	97.1	.26	.52	2.52	52.6
Ohio No. 611	22.9	50.14	1.28	8.42	97.0	.27	.56	2.72	56.8
Ohio No. 619	22.6	50.48	.34	8.21	93.9	.53	.69	3.35	70.0
Ohio No. 904	23.3	65.73	15.25	7.31	84.7	1.32	.25	1.21	45.1
Cumberland	24.5	66.11	.38	6.77	80.1	1.68	.32	1.55	10.6
Ohio No. 920	23.7	66.48	.37	7.46	87.0	1.11	.43	2.09	92.5
Tennessee	25.0	66.53	.05	7.53	89.8	.85	.16	.78	12.4
Ohio No. 933	24.1	67.11	.58	7.18	84.3	1.33	.30	1.46	87.6

OCTOBER 1-15, 1914

Station	Mean water tempera-ture °C.	Pitts-burgh	Sta-tion next above	Parts per million	Per cent satura-tion	Satura-tion deficit (p. p. m.)	Loss during 24 hours incuba-tion at 20° C. (p. p. m.)	Parts per million	Quantity units
Allegheny-7	17.0			8.63	88.7	1.11	0.23	1.12	0.9
Monongahela-12	19.7			5.97	64.8	3.25	.35	1.70	1.4
Ohio No. 3	19.0	2.11	2.11	.72	7.2	8.63	.29	1.41	2.2
Ohio No. 11	18.3	8.34	6.23	6.37	67.2	3.11	.27	1.31	2.2
Ohio No. 19	18.8	12.71	4.37	6.79	72.3	2.60	.19	.92	1.5
Ohio No. 23	17.9	14.60	1.89	6.73	70.4	2.83	.11	.53	.9
Beaver	16.0	15.54	.94	7.94	79.8	1.62	.42	2.04	.5
Ohio No. 65	17.7	25.95	10.41	9.00	93.8	.50	.44	2.14	5.3
Ohio No. 77	18.2	30.69	5.02	8.70	91.6	.80	.33	1.60	4.0
Ohio No. 88	18.6	33.70	2.73	8.45	89.5	.98	.34	1.65	4.1
Ohio No. 97	18.2	36.36	2.66	8.48	89.2	1.02	.38	1.85	4.6
Ohio No. 104	18.1	38.74	2.38	7.83	82.3	1.69	.29	1.41	3.5
Ohio No. 349	20.2	68.38	29.64	8.17	89.5	.96	.38	1.85	8.2
Scioto	19.4	68.83	.45	8.68	93.5	.60	.78	3.79	1.9
Ohio No. 461	20.1	73.25	4.42	8.88	97.2	.27	.37	1.80	13.0
Licking	19.3	74.12	.87	8.04	86.5	1.26	.79	3.84	3.7
Ohio No. 475	20.6	75.07	.95	4.75	52.5	4.31	1.32	6.41	54.0
Ohio No. 482	18.5	76.27	1.20	6.82	72.2	2.62	.84	4.08	34.4
Ohio No. 488	20.1	76.69	.42	6.82	76.0	2.33	.82	3.98	33.5
Ohio No. 492	20.0	76.88	.19	7.03	76.7	2.14	.80	3.88	35.2
Ohio No. 598	19.6	94.68	17.80	9.38	101.5	−.14	.51	2.48	25.8
Ohio No. 611	20.8	98.01	3.33	9.38	103.9	−.35	.73	3.55	37.0
Ohio No. 619	20.8	98.71	.70	9.01	99.8	.02	.73	3.55	37.0
Ohio No. 904	21.3	127.7	29.00	8.31	93.0	.63	.42	2.04	48.3
Cumberland	21.5	128.2	.48	7.17	80.4	.74	.47	2.28	7.6
Ohio No. 920	21.2	128.6	.42	8.33	93.0	.63	.44	2.14	57.8
Tennessee	21.6	128.7	.06	8.35	94.0	.54	.37	1.80	22.1
Ohio No. 933	21.4	129.4	.71	8.03	89.8	.90	.31	1.51	59.4

TABLE No. 51.—*Basic summary of all dissolved oxygen determinations at sampling stations on the Ohio River and tributaries, by months, May, 1914, to April, 1915, inclusive*—Continued

Station	Mean water temperature °C.	Mean time of flow, days from—		Initial dissolved oxygen			Loss during 24 hours incubation at 20° C. (p. p. m.)	Total oxygen demand	
		Pittsburgh	Station next above	Parts per million	Per cent saturation	Saturation deficit (p. p. m.)		Parts per million	Quantity units (p. p. m × thousand second-feet)
OCTOBER, 1914									
Ohio No. 461	18.0	56.72	--------	9.00	94.3	.54	0.66	3.21	40.7
Licking	16.6	57.19	0.47	8.88	90.5	.94	1.05	5.10	18.4
Ohio No. 475	17.8	57.65	.46	6.67	69.6	2.91	1.57	7.62	128.8
Ohio No. 482	17.9	58.35	.70	7.88	82.5	1.68	1.06	5.15	87.0
Ohio No. 488	17.4	58.64	.29	7.79	80.6	1.67	1.04	5.05	85.3
Ohio No. 492	17.1	58.79	.15	8.36	86.1	1.36	1.21	5.87	106.3
Ohio No. 598	18.0	67.40	8.61	8.73	91.6	.81	.44	2.14	47.9
Ohio No. 611	18.1	68.73	1.33	8.92	93.8	.60	.54	2.62	58.6
Ohio No. 619	18.0	69.08	.35	8.64	90.6	.90	.57	2.77	62.0
NOVEMBER, 1914									
Ohio No. 461	7.7	37.20	--------	11.94	99.8	.02	1.90	9.23	105.2
Licking	7.6	37.74	0.54	12.72	106.1	−.73	2.20	10.69	2.5
Ohio No. 475	8.3	38.28	.54	10.69	90.7	1.10	2.44	11.85	139.8
Ohio No. 482	8.3	39.11	.83	11.41	96.8	.38	2.09	10.15	119.8
Ohio No. 488	8.6	39.43	.32	11.03	94.3	.67	1.98	9.62	113.5
Ohio No. 492	8.5	39.60	.17	10.50	89.5	1.23	2.10	10.40	131.0
Ohio No. 598	10.0	50.04	10.44	11.46	101.1	−.13	1.47	7.14	90.6
Ohio No. 611	9.9	52.08	2.04	11.75	103.4	−.39	1.63	--------	--------
Ohio No. 619	10.2	52.60	.52	11.16	99.6	.12	1.46	7.09	87.1
DECEMBER, 1914									
Ohio No. 461	4.7	8.69	--------	11.07	79.7	2.83	1.56	7.58	623.0
Licking	--------	8.82	0.13	10.28	--------	--------	2.44	11.85	72.2
Ohio No. 475	4.7	8.96	.14	11.38	81.9	2.52	2.50	12.14	1070.0
Ohio No. 482	4.6	9.13	.17	11.50	82.6	2.43	2.48	12.05	1063.0
Ohio No. 488	4.9	9.25	.12	11.39	82.4	2.44	2.22	10.78	950.0
Miami	4.2	9.27	.02	12.92	99.0	.14	2.46	11.95	25.8
Ohio No. 492	4.6	9.33	.06	11.49	82.8	2.44	2.51	12.20	1103.0
Ohio No. 598	4.0	11.93	2.60	11.78	89.7	1.35	1.70	8.25	796.0
Ohio No. 611	3.7	12.29	.36	11.84	89.5	1.40	2.06	10.00	965.0
Ohio No. 619	3.6	12.44	.15	12.20	91.9	1.07	2.15	10.45	1008.0
JANUARY, 1915									
Ohio No. 461	1.2	6.42	--------	12.78	90.3	1.37	1.46	7.09	1,219.0
Licking	--------	6.52	0.10	12.60	--------	--------	1.24	6.02	55.8
Ohio No. 475	1.5	6.59	.07	13.30	94.8	.73	2.12	10.30	1,893.0
Ohio No. 482	1.5	6.71	.12	13.26	94.5	.77	1.97	9.56	1,756.0
Ohio No. 488	1.4	6.79	.09	13.18	93.8	.89	1.84	8.92	1,640.0
Miami	1.0	6.81	.02	13.33	93.8	.90	2.08	10.02	39.0
Ohio No. 492	1.3	6.83	.02	13.11	93.0	1.00	1.91	9.27	1,740.0
Ohio No. 598	1.6	8.46	1.59	12.80	91.4	1.20	1.89	9.18	2,036.0
Ohio No. 611	1.5	8.66	.22	12.74	90.8	1.29	1.99	9.65	2,140.0
Ohio No. 619	1.6	8.75	.11	12.67	90.5	1.33	2.02	9.80	2,076.0
FEBRUARY, 1915									
Ohio No. 461	2.7	6.23	--------	12.36	91.0	1.23	1.09	5.30	1,181.0
Little Miami	3.4	6.24	0.01	12.16	91.0	1.18	1.10	5.34	61.4
Licking	--------	6.32	.08	11.64	--------	--------	.64	3.11	33.1
Ohio No. 475	3.3	6.41	.11	12.78	95.5	.60	1.60	7.76	1,900.0
Ohio No. 482	3.2	6.51	.10	12.76	95.1	.65	1.48	7.19	1,760.0
Ohio No. 488	3.2	6.59	.08	12.73	95.0	.68	1.46	7.08	1,735.0
Miami	4.1	6.61	.02	12.38	94.5	.72	1.58	7.67	136.1
Ohio No. 492	3.2	6.64	.13	12.65	94.3	.76	1.57	7.62	2,004.0
Ohio No. 598	3.0	8.07	1.43	12.41	92.2	1.07	1.61	7.81	2,412.0
Ohio No. 611	3.3	8.27	.20	12.51	93.7	.87	1.48	7.19	2,220.0
Ohio No. 619	3.3	8.37	.10	12.47	93.3	.91	1.44	6.99	2,158.0

TABLE No. 51.—*Basic summary of all dissolved oxygen determinations at sampling stations on the Ohio River and tributaries, by months, May, 1914, to April, 1915, inclusive*—Continued

MARCH, 1915

Station	Mean water temperature °C.	Mean time of flow, days from—		Initial dissolved oxygen			Loss during 24 hours incubation at 20° C. (p. p. m.)	Total oxygen demand	
		Pittsburgh	Station next above	Parts per million	Per cent saturation	Saturation deficit (p. p. m.)		Parts per million	Quantity units (p. p. m × thousand second-feet)
Ohio No. 461	3.9	9.26		11.99	91.1	1.17	0.98	4.76	378.0
Little Miami	4.2	9.28	0.02	12.11	92.8	.95	1.02	4.95	3.1
Licking		9.39	.11	12.00			.80	3.88	16.3
Ohio No. 475	4.5	9.53	.14	12.33	92.2	.64	1.48	7.18	604.0
Ohio No. 482	4.5	9.69	.16	12.33	91.9	.64	1.29	6.26	527.0
Ohio No. 488	4.5	9.81	.12	12.29	94.7	.68	1.29	6.26	527.0
Miami	5.2	9.83	.02	11.71	92.0	1.03	1.22	5.92	17.9
Ohio No. 492	4.4	9.89	.06	12.19	93.8	.81	1.38	6.70	584.0
Ohio No. 598	4.7	12.45	2.56	12.21	94.7	1.69	1.41	6.85	676.0
Ohio No. 611	4.9	12.80	.35	12.26	95.5	1.57	1.27	6.17	609.0
Ohio No. 619	4.9	12.95	.15	12.22	95.2	.61	1.15	5.58	551.0

APRIL, 1915

Station	Mean water temperature °C.	Pittsburgh	Station next above	Parts per million	Per cent saturation	Saturation deficit (p. p. m.)	Loss during 24 hours incubation at 20° C. (p. p. m.)	Parts per million	Quantity units
Ohio No. 461	12.3	12.46		10.00	93.0	0.76	0.58	2.82	112.9
Little Miami	14.4	12.49	0.03	9.92	96.5	.36	.68	3.30	.9
Licking		12.65	.16	9.82			.60	2.92	4.0
Ohio No. 475	12.4	12.84	.19	10.19	94.8	.55	1.18	5.72	238.0
Ohio No. 482	12.3	13.10	.26	10.20	94.8	.56	.98	4.76	198.0
Ohio No. 488	12.0	13.27	.17	10.14	93.7	.69	.98	4.76	198.0
Miami	14.4	13.30	.03	10.60	103.1	−.32	1.40	6.80	12.9
Ohio No. 492	11.9	13.37	.07	10.05	92.6	.81	1.18	5.73	249.0
Ohio No. 598	12.8	17.53	4.16	10.41	97.8	.24	.79	3.84	185.3
Ohio No. 611	12.8	18.25	.72	10.83	101.7	−.18	1.03	5.00	241.5
Ohio No. 619	12.8	18.46	.21	10.68	100.3	−.03	1.09	5.29	255.5

CONVERSION OF ANALYTICAL RESULTS INTO UNITS OF TOTAL WEIGHTS CARRIED BY THE RIVER

For certain purposes it is necessary to base comparisons not upon the concentration of a constituent in the river but upon its actual amount, which may readily be calculated knowing the concentration per unit of volume and the discharge of the stream. As concentration is expressed in parts per million (or milligrams per liter), and discharge in second-feet, the simplest expression of relative amounts is the product of concentration in parts per million by discharge in second-feet. This product may then be readily converted into terms of grams per second, per diem, or per annum, for since 1 cubic foot equals 28.317 liters, 1 milligram per liter in a volume represented by a discharge of 1 second-foot equals 28.317 milligrams per second. For convenience of reference this may be called a "second-foot-millionth," as it represents the amount necessary to give a concentration of 1 part per million in a discharge of 1 second-foot. Similarly, the amount, 28,317 milligrams per second, necessary to give a concentration of 1 part per thousand in a discharge of 1 second-foot, or one part per million in 1,000 second-feet, may be called a "second-

foot-thousandth." This latter unit, obtained as the product of parts per million by thousands of second-feet, is a convenient one for many uses. Its equivalents in other more common terms are as follows:

1 "second-foot-thousandth"	=	the amount which will add 1 part per million to a discharge of 1,000 second-feet;
	= 28.317	grams per second;
	= 2,446,589	grams per day;
	= 893,005	kilograms per year;
	= 5,393.69	pounds per day;
	= 1,968,719	pounds per year;
	= 878.89	long tons per year.

The unit "second-foot-thousandth" possesses no advantage over these equivalents except that it is derived more directly from the data at hand and is less unwieldy.

PRECISION OF ANALYTICAL RESULTS

One of the chief purposes which the chemical analyses serve is to indicate the direction and measure the extent of differences between conditions at different sampling stations at a given time, or at the same sampling station at different times, relating the observed differences to some determinable cause, such as the inflow of sewage from a known source or the operation of natural agencies of purification. For the interpretation of the results in such applications, or, indeed, in any light, it is necessary to have some idea of their precision, in order to judge whether observed differences are significant of actual changes in conditions or are attributable merely to chance variations in the observations. The errors to which the observations are subject are, however, rather complex.

To consider them in reverse order, there is, first, the error in the actual analysis of the sample. While a chemical analysis is a fairly exact procedure as compared with many biological observations, it nevertheless has its limits of precision. Aside from variations due to differences in the technique and judgment of different analysts, each determination has a more or less well-defined limit of delicacy, in respect of which different determinations vary widely. For instance, while the determination of nitrites is ordinarily carried to the nearest thousandth of a milligram, alkalinity is determined only to the nearest tenth, and turbidity only to the nearest milligram per liter, and in most determinations the last significant digit used in expressing the result is an interpolation. In general, the inherent error in any chemical determination is not a constant part of a milligram per liter, nor is it a constant proportion of the total, since the absolute error (in milligrams per liter) tends to decrease, and the relative error, expressed as a ratio to the total, tends to increase

as the limits of the delicacy of the determination are approached. It should be possible, by taking into account the details of procedure employed, to deduce with reasonable accuracy the probable error inherent in various chemical determinations. However, it would not be profitable to undertake any such *a priori* deduction of the probable analytical error in the determinations made in this study, where other factors come in, such as minor differences in technique and judgment of the several chemists by whom the analyses were made.

Again, there is obviously an error involved in the assumption that the sample collected from one or more points on a cross section of a stream accurately represents the whole volume of water passing that section at the time. The perfect vertical and lateral mixture thus assumed is never realized, and while it may be approximated at some sampling stations remote from any upstream source of considerable pollution, it may be far from the true condition at a cross section located a short distance below the outlet of a large sewer or tributary. Nor may it safely be assumed that this sampling error at a given cross section is a random error, tending to compensation. It may well be, and at some stations probably is, a systematic error, tending constantly to give a too high or too low concentration in the sample.

Beyond this, there is the further error in the assumption that the water passing a given section at the time of sampling is a fair sample of all the water passing the section in the interval of a day or more which that sample is taken to represent. Actually, the chemical characteristics of a river water vary widely, suddenly, and irregularly with changes in river stage and in the proportionate inflow from various sources, so that the variation, even within 24 hours, may be considerable. This error, however, is presumably balanced over any considerable period of time.

Where results are expressed in absolute amounts of constituents carried, as calculated from concentration and discharge, still another possible error is introduced, namely, that of the discharge estimates.

Because of these complexities, the net probable error of a single determination or a series of determinations can not be deduced with any degree of confidence, but it may be at least approximated by a study of the observed differences between values independently obtained, which, if precisely determined, should be equal. However, the available data afford but few sets of observations which may properly be compared on the assumption that the differences observed are due solely to errors in the observations.

Perhaps the best data for such purpose are afforded by the observations on the Ohio River immediately above the mouth of the Scioto, as compared with the Scioto and the Ohio River below the junction

f the latter. The distance between the sampling station above the cioto (station 348) and that below the Scioto (station 358) is short; he velocity in this stretch is relatively high, so that the maximum ime of flow during the months of observation was only about 13 ours, usually less than half this long, and between the two sections he Ohio receives no inflow of consequence except through the Scioto. Such wastes as are discharged into the river in this stretch from the artly sewered city of Portsmouth may be disregarded as being nsufficient to affect measurably the chemical content of such a large tream as the Ohio.

The amount of any constituent carried by the Ohio at station 358, elow the Scioto, determined in "second-foot-thousandths" (parts er million × thousands of second-feet) should equal the amount arried by the Ohio at station 348 plus the amount carried by the Scioto.[1]

A comparison of these values, which should be equal, is presented n Table No. 52, which shows, for each of the six determinations ncluded:

(*a*) The monthly mean amounts carried by the Ohio at station 358.

(*b*) The sums of the monthly mean amounts carried by the Scioto nd by the Ohio at station 348.

(*c*) The means of (*a*) and (*b*) $\left(\frac{a+b}{2}\right)$.

(d_1) The differences $(a-b)$, with positive or negative sign according as (*a*) is greater or less than (*b*).

(d_2) The differences $(a-b)$ expressed as percentages of the mean [$(a-b) \div \left(\frac{a+b}{2}\right) \times 100$.]

[1] The discharge at station 358 is not independently estimated, being taken as the sum of the discharges of the Scioto and of the Ohio above the Scioto.

TABLE No. 52.—*Amounts of various chemical constituents carried by the Ohio River at station 358, compared with the sums of amounts carried by the Scioto River and the Ohio at station 348*

[Calculations based on monthly means of chemical analyses and discharges [1]]

Month	Parts per million multiplied by discharge in thousands of second-feet														
	Hardness [2]					Alkalinity [2]					Chlorine [2]				
	Station 358 (a)	Station 348+ Scioto (b)	Mean $\frac{a+b}{2}$ (c)	Difference $(a-b)$ (d)	Ratio $\frac{d}{c}\times 100$ (d_2)	Station 358 (a)	Station 348+ Scioto (b)	Mean $\frac{a+b}{2}$ (c)	Difference $(a-b)$ (d)	Ratio $\frac{d}{c}\times 100$ (d_2)	Station 358 (a)	Station 348+ Scioto (b)	Mean $\frac{a+b}{2}$ (c)	Difference $(a-b)$ (d)	Ratio $\frac{d}{c}\times 100$ (d_2)
1914															
January	5, 990	6, 595	6, 293	−605	−9. 6	2, 080	2, 782	2, 431	−702	−28. 9	1, 450	1, 407	1, 428	+43	+3. 1
February	8, 160	8, 660	8, 410	−500	−5. 9	2, 740	4, 000	3, 370	−1, 260	−37. 4	1, 400	1, 439	1, 420	−39	−2. 7
March	9, 700	9, 910	9, 805	−210	−2. 1	3, 650	4, 470	4, 060	−820	−20. 2	3, 650	4, 470	4, 060	−820	−20. 2
April	11, 500	13, 630	12, 565	−2, 130	−17. 0	4, 320	5, 630	4, 975	−1, 310	−26. 3	4, 320	5, 630	4, 975	−1, 310	−26. 3
May	8, 310	6, 700	7, 505	+1, 610	+21. 5						1, 380	1, 064	1, 222	+316	+25. 9
June	2, 400	2, 320	2, 360	+80	+3. 4	1, 210	1, 002	1, 106	+208	+18. 8	472	579	526	−107	−20. 3
July	2, 280	1, 671	1, 976	+609	+30. 8	980	760	870	+220	+25. 3	556	588	572	−32	−5. 6
August	1, 560	1, 501	1, 530	+59	+3. 9	768	635	702	+133	+18. 9	397	415	406	−18	−4. 4
September	2, 060	1, 898	1, 979	+162	+8. 2	812	662	737	+150	+20. 4	609	526	567	+83	+14. 6
October	666	613	639	+53	+8. 3	385	313	349	+72	+20. 6	168	176	172	−8	−4. 6

Month	Parts per million multiplied by discharge in thousands of second-feet														
	Organic nitrogen [3]					Mineral nitrogen [4]					Oxygen consumed				
	Station 358 (a)	Station 348+ Scioto (b)	Mean $\frac{a+b}{2}$ (c)	Difference (a−b) (d)	Ratio $\frac{d}{c}\times100$ (d_2)	Station 358 (a)	Station 348+ Scioto (b)	Mean $\frac{a+b}{2}$ (c)	Difference (a−b) (d)	Ratio $\frac{d}{c}\times100$ (d_2)	Station 358 (a)	Station 348+ Scioto (b)	Mean $\frac{a+b}{2}$ (c)	Difference (a−b) (d)	Ratio $\frac{d}{c}\times100$ (d_2)
1914															
January	48.66	45.99	47.33	+2.67	+5.6	52.09	51.13	51.61	+.96	+1.9	401.0	376.4	388.7	+24.6	+6.3
February	134.63	119.07	126.85	+15.56	+12.3	85.66	99.94	92.80	−14.28	−15.4	1,070.0	992.0	1,031.0	+78.0	+7.6
March	113.46	117.77	115.62	−4.31	−3.7	75.11	91.27	83.19	−16.16	−19.4	715.0	707.0	711.0	+8.0	+1.1
April	146.12	139.93	143.02	+6.19	+4.3	100.91	102.21	101.56	−1.30	−1.3	931.0	790.0	860.5	+141.0	+16.4
May	71.20	78.37	74.78	−7.17	−9.6	29.31	28.94	29.12	+.37	+1.3	604.0	491.1	547.5	+112.9	+20.6
June	9.59	7.94	8.76	+1.65	+18.8	3.43	4.38	3.90	−.95	−24.4	52.0	31.4	41.7	+20.6	+49.4
July	8.53	11.78	10.16	−3.25	−32.0	6.51	6.08	6.30	+.43	+6.8	42.7	50.4	46.6	−7.7	−16.5
August	6.80	8.51	7.66	−1.71	−22.3	3.51	3.26	3.38	+.25	+7.4	53.0	63.4	58.2	−10.4	−17.9
September	9.54	13.14	11.34	−3.60	−31.7	4.32	4.83	4.58	−.51	−11.1	57.8	57.2	57.5	+0.6	+1.0
October	2.31	3.33	2.82	−1.02	−36.2	1.44	1.49	1.46	−.05	−3.4	15.4	18.4	16.9	−3.0	−17.7

[1] For basic data and number of samples entering into monthly means, see Table 50.

[2] Monthly means of hardness, alkalinity and chlorine for months January–April, derived from examination of semiweekly samples, same as used for determinations of organic constituents. Thereafter (May–October) they are the results of monthly analyses of samples composited from daily collections.

[3] Organic nitrogen for months January–August, calculated as equal to N as free ammonia + 3 times N as albuminoid ammonia. For September and October, organic N calculated as equal to N as free ammonia + Kjeldahl N.

[4] Mineral N=N as nitrates + N as nitrites.

The individual deviations vary from 1.1 to 49.4 per cent, the average deviations for the several determinations varying from ± 9.2 to ± 24.1 per cent.

In Table No. 53 all the deviations (d_2), without distinction as to the determinations from which they are derived, are assembled in a distribution according to sign and magnitude. From this it is seen that positive and negative deviations are as nearly balanced as possible, there being 29 of positive and 30 of negative sign, indicating that in this example the errors, including those of analysis, sampling, and discharge, are compensatory.

TABLE No. 53.—*Distribution of deviations (d_2) as shown in Table No. 52*

]Per cent of mean]

Class	Frequency		
	+	−	Total
0–4.9 per cent	8	7	15
5–9.9 per cent	7	4	11
10–14.9 per cent	2	1	3
15–19.9 per cent	4	6	10
20–24.9 per cent	4	5	9
25–29.9 per cent	2	3	5
30–34.9 per cent	1	2	3
35–39.9 per cent	0	2	2
40–44.9 per cent	0	0	0
45–49.9 per cent	1	0	1
Total	29	30	59

Standard deviation of difference: $\sigma_{a-b}=18.45$ per cent.
Probable error of differences: $e_{a-b}=\pm 12.45$ per cent.
Probable error of monthly mean: $e_a=e_b=\pm 8.80$ per cent.

The "probable error," that is the range within which one-half the errors would be expected to fall, in a large number of observations, is computed from the data of Table No. 53 by the general formula

(1) $e=0.67449\sigma$, where

$e=$ the probable error, and

$\sigma=$ the standard deviation of the observed distribution.

In this case the error thus computed is not the error of a monthly mean but the error of the *difference between two monthly means*, (a) and (b), expressed as a percentage of their mean; and bears to the separate errors of (a) and (b), respectively, the relation:

(2) $e_{a-b}=\sqrt{e_a^2+e_b^2}$ where,

e_a = the probable error of (a),

e_b = the probable error of (b),

e_{a-b} = the probable error of the difference ($a-b$).

If it be assumed in this case that the errors of (a) and (b) are equal, then:

(3) $e_{a-b}=\sqrt{e_a^2+e_b^2}=\sqrt{2e_a^2}=e_a\sqrt{2}$

(4) $e_a \quad = e_b \qquad = \dfrac{e_{a-b}}{\sqrt{2}}$, and

the values derived from the observed deviations (d_2) distributed as shown in Tables 52 and 53, according to these formulae, are:

Standard deviation of differences: $\sigma_{a-b} = 18.45$ per cent

Probable error of differences: $e_{a-b} = \pm 12.45$ per cent

Probable error of monthly mean:[2] $e_a = e_b = \pm 8.80$ per cent

The significance of these probable errors, according to the accepted mathematical theory upon which they are based, is that the difference between the values of monthly means (a) and (b) which, in the absence of any error, would be equal to zero, is as likely as not to be within the range ± 12.45 per cent of their mean, provided the differences are due entirely to random or chance errors. Or, in other words, in a sufficiently large series of observations, half the differences $(a-b)$ would fall within the range ± 12.45 per cent of their mean.[3] Similarly, as regards the separate values, (a) and (b), their probable error signifies[2] that an observed monthly mean at station No. 358, or at stations 348 and the Scioto, is as likely as not to differ from the true value by ± 8.80 per cent. Considering the small number of observations, the heterogeneous character of the chemical determinations considered, the variable number of separate samples included in the monthly means used, and that certain of the assumptions made are probably not literally true, the computed "probable errors" should not be taken too literally. They are to be taken as an indication rather than a measure of the probable variation due to the combined errors of analysis, sampling and discharge.

The monthly means of chemical analyses at stations 348, 358, and the Scioto River which have been considered above are computed from an average of 6.5 separate analyses each month at each station.[4] Table No. 54 presents a similar study of monthly mean turbidities at station 358 as compared with station 348 and the Scioto River. In this case each monthly mean at each station is based upon an average of 23 individual determinations; and, other conditions being comparable, the probable error should be less than that of means based on smaller numbers of separate observations. The result, probable errors of ± 5.63 per cent as applying to the separate monthly means, and $\pm$ 7.97 per cent as applying to their differences, is consistent, in that the probable errors are slightly smaller than in the case of the monthly means in Table No. 52, where the frequency of sample collection is considerably less. It is to be noted, however, that the differences in Table No. 54, are, with one exception, of positive sign, suggesting that there is a constant tendency toward higher turbidity readings at station 358 than at station 348 and in the Scioto.

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[2] Depends upon the assumption that the two errors are equal, which is not necessarily the case.

[3] Actually 28 of the 59 deviations fall within this range.

[4] Except as to alkalinity and hardness, which, during a part of this period, were determined from monthly analyses of samples composited from daily collections.

TABLE No. 54.—*Amounts of turbidity (suspended matter) carried by the Ohio River at station 358, compared with the sums of amounts carried by the Scioto River and the Ohio River at station 348*

[Calculations based on monthly mean turbidities and discharges]

Month	Turbidity, silica scale × thousand second-feet				
	Station 358 (*a*)	Station 348 and Scioto (*b*)	Mean $\frac{(a+b)}{2}$ (*c*)	Difference $(a-b)$ (d_1)	Ratio $\frac{d}{c}\times 100$ (d_2)
1914					
January	6, 821	5, 655	6, 238	+1, 166	+18. 7
February	26, 483	25, 434	25, 959	+1, 049	+4. 0
March	19, 773	19, 268	19, 520	+505	+2. 6
April	37, 034	35, 381	36, 208	+1, 653	+4. 6
May	16, 948	16, 450	16, 699	+498	+3. 0
June	643	628	635	+15	+2. 4
July	1, 353	1, 687	1, 520	−334	−22. 0
August	1, 506	1, 229	1, 367	+277	+20. 2
September	1, 291	1, 175	1, 233	+116	+9. 4
October	118	115	117	+3	+2. 6
Mean					±8. 9

Standard deviation of differences; $\sigma_{a-b} = \pm 11.81$ per cent
Probable error of differences; $e_{a-b} = \pm 7.97$ per cent
Probable error of monthly mean; $e_a = e_b = \pm 5.63$ per cent

An opportunity for another similar study is afforded by observations of turbidity in the Miami River, and in the Ohio River at stations 488, immediately above, and 492, immediately below the junction of the Miami. Samples were collected from these three stations for a period of 33 months, from April, 1914, to December, 1916, inclusive. During approximately half of this period, from December, 1914, to March, 1916, samples were collected five times each week, except as the schedule was accidentally interrupted, giving an average of about 22 samples a month. During the remainder of the period samples were collected usually three days each week, collection being made on the same days from all three stations. This schedule, with occasional accidental interruptions, gave an average of about 10 collections a month from each station.

Results at station 492 as compared with station 488 plus the Miami River are shown in Table No. 55, which is similar to Tables Nos. 52 and 54, above. The deviations in column (d_2) of Table No. 55 are assembled in order of sign and magnitude in Table No. 56. The positive and negative deviations are nearly balanced, and with respect to magnitude, the distribution of the deviations is fairly symmetrical. The probable errors of the differences $(a-b)$ and of the monthly means (a) or (b), ± 9.38 and ± 6.63 per cent, respectively, are of the same order of magnitude as those determined in the two preceding examples.

TABLE No. 55.—*Amount of turbidity (suspended matter) carried by the Ohio River at Station 492, compared with the sum of the amounts carried by the Miami River and the Ohio River at station 488*

Calculations based on monthly mean turbidities and discharges, April, 1914, to December, 1916

Month	Turbidity, silica scale×discharge				
	492 (a)	488 + Miami (b)	Mean $\frac{a+b}{2}$ (c)	Difference (a−b) (d)	Per cent $\frac{d}{c}\times 100$ (d_2)
1914					
April	38, 820, 400	33, 107, 400	35, 963, 900	+5, 713, 000	+15. 9
May	24, 259, 980	22, 154, 870	23, 207, 425	+2, 105, 110	+9. 1
June	1, 045, 280	1, 372, 760	1, 209, 020	−327, 480	−27. 1
July	1, 120, 000	787, 000	923, 500	+393, 000	+42. 6
August	2, 141, 100	2, 617, 550	2, 379, 325	−476, 450	−20. 0
September	1, 687, 280	1, 565, 480	1, 626, 380	+121, 800	+7. 5
October	3, 120, 080	2, 123, 020	2, 621, 550	+997, 060	+38. 0
November	150, 984	171, 386	161, 185	−20, 402	−12. 7
December	27, 198, 360	28, 568, 520	27, 883, 440	−1, 370, 160	−4. 9
1915					
January	49, 922, 540	50, 020, 840	49, 971, 690	−98, 300	−. 2
February	37, 588, 980	36, 026, 040	36, 807, 510	+1, 562, 940	+4. 2
March	7, 152, 860	7, 948, 770	7, 550, 815	−795, 910	−10. 5
April	1, 218, 000	1, 159, 500	1, 188, 750	+58, 500	+4. 9
May	19, 299, 520	17, 726, 360	18, 512, 940	+1, 573, 160	+8. 5
June	30, 584, 610	34, 050, 580	32, 317, 595	−3, 465, 970	−10. 7
July	64, 961, 500	58, 736, 000	61, 848, 750	+6, 225, 500	+10. 1
August	19, 999, 680	16, 718, 160	18, 358, 920	+3, 281, 520	+17. 9
September	10, 822, 500	19, 420, 300	15, 121, 400	−8, 597, 800	−5. 7
October	13, 130, 250	12, 091, 940	12, 611, 095	+1, 038, 310	+8. 2
November	4, 898, 790	5, 599, 840	5, 249, 315	−701, 050	−13. 4
December	30, 804, 840	30, 508, 740	30, 656, 790	+296, 100	+1. 0
1916					
January	104, 655, 600	98, 535, 680	101, 595, 640	+6, 119, 920	+6. 0
February	60, 004, 360	55, 051, 160	57, 527, 760	+4, 953, 200	+8. 6
March	89, 852, 820	92, 534, 940	91, 193, 880	−2, 682, 120	−2. 9
April	25, 302, 740	23, 679, 580	24, 491, 160	+1, 623, 160	+6. 6
May	17, 092, 832	16, 035, 680	16, 564, 256	+1, 057, 152	+6. 4
June	37, 794, 069	38, 309, 216	38, 051, 642	−515, 147	−1. 4
July	10, 167, 850	10, 855, 050	10, 511, 450	−687, 200	−6. 5
August	16, 828, 376	16, 997, 808	16, 913, 092	−169, 432	−1. 0
September	956, 437	882, 342	919, 389	+74, 095	+8. 1
October	1, 715, 754	1, 774, 592	1, 745, 173	−58, 838	−3. 4
November	300, 192	297, 382	298, 787	+2, 810	+. 9
December	10, 404, 000	11, 136, 255	10, 770, 127	−732, 255	−6. 8
Mean					±10. 05

NOTE.—The mean turbidity (95 parts per million) at station 492 for the month of July, 1914, is unduly influenced by the reading of 400 parts per million on one day, July 14, when the high turbidity at that station resulted from an unusual freshet on the Miami, not affecting the turbidity at station 488. On that date, when the turbidity of the Miami was very high, no sample was obtained from the Miami, hence the mean turbidity of the Miami for the month is not properly comparable to that of station 492. In this computation the result of that single day's observation at station 492 is omitted, reducing the mean turbidity for the month from 95 to 56 parts per million. Inclusion of this one observation would have the effect of increasing the probable errors by about two-thirds.

TABLE No. 56.—*Distribution of deviations (d_2) shown in Table No. 55*

Class	Frequency		
	+	−	Total
0–4.9 per cent	4	6	10
5–9.9 per cent	9	3	12
10–14.9 per cent	1	4	5
15–19.9 per cent	2	0	2
20–24.9 per cent	0	1	1
25–29.9 per cent	0	1	1
30–34.9 per cent	0	0	0
35–39.9 per cent	1	0	1
40–44.9 per cent	1	0	1
45 and over	0	0	0
Total	18	15	33

Standard deviation of differences; $\sigma_{a-b}=13.91$ per cent
Probable error of differences; $e_{a-b}=\pm 9.38$ per cent
Probable error of monthly mean; $e_a=e_b=\pm 6.63$ per cent

In the foregoing examples the errors which have been calculated are compound or net errors, including the separate errors of analysis, of sampling and of discharge estimates. The analytical error alone could be experimentally determined quite satisfactorily from a sufficient series of duplicate analyses of identical samples; but no such series of duplicate analyses has been made in the course of this study. Data are available, however, for comparison of alkalinity determinations as derived from:

(1) The monthly means of separate analyses of the samples collected each day; and

(2) The final, and single analysis, each month, of a composite sample made up by taking an equal portion of each separate sample as delivered to the laboratory.

The samples in these two series from any given sampling station are identical, and, assuming that no change takes place in the alkalinity as the result of storage of the composited sample, the two sets of observations should give identical results but for errors in the analytical procedure.

A comparison of these parallel determinations from six sampling stations on the Ohio and its tributaries, for such periods as are covered by the records, is shown in Table No. 57, which is similar in arrangement and purpose to those previously presented, except that results are expressed in parts per million, taking no account of the discharge factor which is the same in each pair of observations. The distribution of the deviations between each pair of monthly means is shown in Table No. 58, together with the standard deviation and the probable error calculated therefrom.

TABLE No. 57.—*Comparison of monthly mean alkalinities at various stations on the Ohio River and tributaries as determined by: (a) Averaging results of separate determinations upon each sample; and (b) analyses of monthly composite samples*

Month	Station 461, Ohio					Station 482, Ohio					Station 598, Ohio				
	Alkalinity, p. p. m.				Ratio $\frac{d}{c} \times 100$	Alkalinity, p. p. m.				Ratio $\frac{d}{c} \times 100$	Alkalinity, p. p. m.				Ratio $\frac{d}{c} \times 100$
	Result of separate analysis (a)	Analysis of monthly composite (b)	Mean $\frac{a+b}{2}$ (c)	Difference (a−b) (d)	(d_2)	Result of separate analysis (a)	Analysis of monthly composite (b)	Mean $\frac{a+b}{2}$ (c)	Difference (a−b) (d)	(d_2)	Result of separate analysis (a)	Analysis of monthly composite (b)	Mean $\frac{a+b}{2}$ (c)	Difference (a−b) (d)	(d_2)
1914															
May	31	32	31.5	−1	−3.2	35	37	36	−2	−5.6	39	42	40.5	−3	−7.4
June	56	59	57.5	−3	−5.2	63	65	64	−2	−3.1	64	73	68.5	−9	−13.1
July	53	55	54	−2	−3.7	58	58	58	0	0	71	74	72.5	−3	−4.1
August	53	42	47.5	+11	+23.2	60	63	61.5	−3	−4.9	69	73	71	−4	−5.6
September	50	47	48.5	+3	+6.2	55	53	54	+2	+3.7	66	62	64	+4	+6.2
October	63	69	66	−6	−9.1	69	69	69	0	0	79	83	81	−4	−4.9
November	67	69	68	−2	−2.9	77	74	75.5	+3	+4.0	90	88	89	+2	+2.2
December	48	43	45.5	+5	+11.0	51	50	50.5	+1	+2.0	61	57	59	+4	+6.8
1915															
January	26	25	25.5	+1	+3.9	29	30	29.5	−1	−3.4	36	38	37	−2	−5.4
February	27	29	28	−2	−7.1	30	29	29.5	+1	+3.4	39	43	41	−4	−9.8
March	33	34	33.5	−1	−3.0	37	36	36.5	+1	+2.7	47	47	47	0	0
April	37	40	38.5	−3	−7.8	40	45	42.5	−5	−11.8	47	50	48.5	−3	−6.2
May						46	51	48.5	−5	−10.3	54	59	56.5	−5	−8.8
June						50	56	53	−6	−11.3	63	67	65	−4	−6.2
July						61	60	60.5	+1	+1.7	74	80	77	−6	−7.8
August						67	65	66	+2	+3.0	84	82	83	+2	+2.4
September						73	73	73	0	0	87	88	87.5	−1	−1.1
October						55	54	54.5	+1	+1.8	66	68	67	−2	−3.0
November						58	55	56.5	+3	+5.3	72	72	72	0	0
December						48	49	48.5	−1	−2.1	57	57	57	0	0

TABLE No. 57.—*Comparison of monthly mean alkalinities at various stations on the Ohio River and tributaries as determined by: (a) Averaging results of separate determinations upon each sample; and (b) analyses of monthly composite samples*—Continued

Month	Little Miami River					Licking River					Miami River				
	Alkalinity, p. p. m.				Ratio $\frac{d}{c} \times 100$	Alkalinity, p. p. m.				Ratio $\frac{d}{c} \times 100$	Alkalinity, p. p. m.				Ratio $\frac{d}{c} \times 100$
	Result of separate analysis (a)	Analysis of monthly composite (b)	Mean $\frac{a+b}{2}$ (c)	Difference $(a-b)$ (d)	(d_2)	Result of separate analysis (a)	Analysis of monthly composite (b)	Mean $\frac{a+b}{2}$ (c)	Difference $(a-b)$ (d)	(d_2)	Result of separate analysis (a)	Analysis of monthly composite (b)	Mean $\frac{a+b}{2}$ (c)	Difference $(a-b)$ (d)	(d_3)
1914															
May	186	187	186.5	−1	−0.5	70	72	71	−2	−2.8	221	207	214	+14	+6.5
June						79	81	80	−2	−2.5					
July						88	88	88	0	0					
August	173	153	163	+20	+12.3	90	85	87.5	+5	+5.7	176	152	164	+24	+14.6
September	186	181	183.5	+5	+2.7	86	90	88	−4	−4.5	205	215	210	−10	−4.8
October						87	89	88	−2	−2.3					
November	235	228	231.5	+7	+3.0	113	108	110.5	+5	+4.5	251	246	248.5	+5	+2.0
December	196	207	201.5	−11	−5.5	103	99	101	+4	+4.0	246	230	238	+16	+6.7
1915															
January	113	98	105.5	+15	+14.2	76	75	75.5	+1	+1.3	183	183	183	0	0
February	163	154	158.5	+9	+5.7	87	81	84	+6	+7.1	182	165	173.5	+17	+9.8
March	210	202	206	+8	+3.9	76	81	78.5	−5	−6.4	225	225	225	0	0
April	216	216	216	0	0	77	80	78.5	−3	−3.8	232	235	233.5	−3	−1.3
May	226	210	218	+16	+7.3	97	96	96.5	+1	+1.0	219	216	217.5	+3	+1.4
June						104	110	107	−6	−5.6	211	208	209.5	+3	+1.4
July						81	80	80.5	+1	+1.2	197	180	188.5	+17	+9.0
August						95	91	93	+4	+4.3	211	199	205	+12	+5.9
September						142	139	140.5	+3	+2.1	227	220	223.5	+7	+3.1
October						90	88	89	+2	+2.2	238	224	231	+14	+6.1
November						88	90	89	−2	−2.2	244	240	242	+4	+1.7
December						83	87	85	−4	−4.7	212	204	208	+8	+3.8

TABLE No. 58.—*Distribution of deviations (d_2) shown in Table No. 57*

Class	Frequency +	Frequency −	Frequency Total
0–1.9	8	3	21
2–3.9	16	13	29
4–5.9	8	12	20
6–7.9	8	7	15
8–9.9	2	3	5
10–11.9	1	3	4
12–13.9	1	1	2
14–15.9	2	0	2
22–23.9	1	0	1
Total	47	42	[1] 99

[1] Includes 10 observations with zero deviation.

Standard deviation of differences; $\sigma_{a-b} = 6.100$ per cent.
Probable error of differences; $e_{a-b} = 4.114$ per cent.
Probable error of monthly means; $e_a = e_b = 2.910$ per cent.

As in the preceding illustration, the errors are well balanced, there being 47 positive as against 42 negative deviations, indicating that there is no tendency toward a consistently higher result by either procedure. As is to be expected, because of the elimination of errors of sampling and discharge from this comparison, the probable errors are considerably less than in previously cited examples. Considering that the daily determinations and the monthly composite analyses were frequently made by different chemists, the agreement is quite close.

While none of the foregoing analyses, taken separately, may have any great weight as indicating the probable error of monthly mean chemical determinations in general, as made in this investigation, the whole series, taken together, have considerably more significance by reason of their consistency. They afford at least some reasonable and concrete idea of the degree of precision of the analytical data, emphasizing what would already be sufficiently obvious to a careful student of the data, that the observations are not sufficiently precise to be applied to the measurement of slight variations within a range of, say, 10 to 20 per cent. At the same time they serve to give more confidence in the data as applied to the measurement and interpretation of consistent and rational variations well beyond this range. The assumption of a probable error of about ± 10 per cent in monthly means is further justified by the general agreement as to direction and extent between observed and expected changes which take place between consecutive sampling stations. For instance, it is obvious that the total nitrogen content of the Ohio River must be increased in passage past Cincinnati, where it receives the sewage of some 500,000 people. The amount of nitrogen contained in the domestic sewage and industrial wastes can be estimated with a reasonable approximation to accuracy, and knowing the discharge of

the river, it is possible to calculate the expected increase in parts per million of nitrogen in the river water. When the river is at high stage and the expected increase in its total nitrogen is less than about 10 per cent, observations above and below the city sometimes show an actual decrease in passage past the city, an irrational result, obviously attributable to error in the observations. But when the river is at such low stage that the expected increase in concentration would amount to as much as 20 per cent or more of that in the stream above the city, such irrational results are very infrequent.

INORGANIC CONSTITUENTS

I. Turbidity

The turbidity of water, as determined by standard photometric methods, is a measure of the interference which the water offers to the passage of light, due to the presence of finely divided suspended matter. The determination is of importance in the examination of surface waters chiefly because it affords a rough index of the amount of suspended matter present, and because it is a much simpler procedure than a gravimetric determination. Since the suspended matter which causes turbidity in surface waters such as those of the Ohio River system consists largely of soil particles thrown into the stream by surface erosion, the determination of its varying amounts, when correlated with other conditions, affords almost the only available index of the extent to which these conditions are affected by surface erosion as compared with pollution from other sources. Also, determinations of turbidity are of great practical importance in relation to the methods, economy, and efficiency of water purification, being among the most frequent and essential determinations made in connection with the control of purification processes involving clarification.

The arbitrarily established standard,[5] taken as representing a turbidity of 100 is:

"a water which contains 100 parts per million of silica in such a state of fineness that a bright platinum wire 1 millimeter in diameter can just be seen when the center of the wire is 100 millimeters below the surface of the water and the eye of the observer is 1.2 meters above the wire, the observation being made in the middle of the day, in the open air, but not in sunlight, and in a vessel so large that the sides do not shut out the light so as to influence the results."

The scale of turbidity above and below this point (100, is so chosen that readings upon the scale indicate the weight, in parts per million, of standard silica required to produce the corresponding degrees of turbidity.

[5] Standard Methods for the Examination of Water and Sewage. Am. Pub. Health Assn., Boston, 1920, 4th ed., p. 4

Coefficient of fineness.—This direct relation between turbidity and weight of suspended matter applies, however, only to material of the same fineness, specific gravity, and optical properties as the silica used in making the standard suspension. Other things being equal, the turbidity decreases as the size of particles is increased, though not in direct proportion; and, as an index of this relation, the Standard Methods define a "coefficient of fineness" as the ratio of the weight of suspended matter in parts per million to turbidity expressed in the standard scale. Assuming that other conditions affecting the relation of suspended matter to turbidity are constant, a "coefficient of fineness" greater than unity indicates that the particles in suspension are coarser than the standard, and vice versa. The coefficient of fineness is not to be understood, however, as indicating directly the relative size of particles as compared with the standard.

Although no very comprehensive studies of the subject appear to have been made, experience in this country indicates that the turbidity of surface waters, expressed according to this standard scale, is very nearly the same as the weight of the suspended matter when the latter is independently determined, the agreement being generally closer with relatively high turbidities (over 100) than with low turbidities (less than 25).

In a study of the Mississippi River water at New Orleans, based on samples collected daily from December 10, 1900, to August 10, 1901, Weston [6] found that the average value of the coefficient of fineness was 1.08. The turbidity during this study was relatively high, ranging from 95 to 1,300, and averaging 406. The coefficient of fineness was found, as would be expected, to decrease progressively in river water held in settling basins, due presumably to the more rapid sedimentation of the coarser particles. Thus, the coefficients of fineness after periods of subsidence are given as follows: [7]

Character of water:	Coefficient of fineness
Raw Mississippi River water	1.08
Same, after 6 hours' subsidence	.90
Same, after 12 hours' subsidence	.87
Same, after 18 hours' subsidence	.86
Same, after 24 hours' subsidence	.85
Same, after 48 hours' subsidence	.80
Same, after 72 hours' subsidence	.76
Same, after 24 hours' subsidence and coagulation	.60

Ellms [8] found the average value of the coefficient of fineness in waters of the Ohio River at Cincinnati to be 1.12, based upon daily samples during the year 1914. The monthly mean results of his observations are as shown in Table No. 59.[9]

[6] Report on Water Purification Investigation and on Plans Proposed for Sewerage and Waterworks Systems. A. W. Hyatt Co., pub., New Orleans, 1903, pp. 23–45.
[7] Ibid., p. 28.
[8] Quoted by Flinn, Weston & Bogert. Waterworks Handbook, McGraw-Hill, New York, 1918, 1st ed., p. 664.
[9] Rearranged from Table, loc. cit.

TABLE NO. 59.—*Turbidity, weight of suspended matter, and coefficient of fineness in water of the Ohio River at Cincinnati*

[Monthly means]

Month	Turbidity	Weight of suspended matter (parts per million)	Coefficient of fineness	Month	Turbidity	Weight of suspended matter (parts per million)	Coefficient of fineness
1914				1914			
December	300	346	1.15	September	100	119	1.19
February	235	228	.97	January	95	137	1.44
April	155	178	1.15	October	70	90	1.29
March	145	162	1.12	July	17	39	2.29
August	145	103	.71	June	11	46	4.18
May	140	146	1.04	November	9	24	2.67

According to these observations the ratio of suspended matter to turbidity ranged rather closely around 1.0 (average = 1.09) during the nine months in which the turbidity averaged 70 or more, but departed widely from this ratio in the three months with mean turbidities under 20. Applying the usual interpretation, that the coefficient of fineness is an index of the size of the suspended particles, one is led to the paradoxical inference that the suspended matter was coarser during the months of low turbidity, when the river was at low stages and of very low velocity, than during the months of high turbidity when the stream velocity was generally much higher. The explanation of the seeming paradox probably lies in the different character and origin of the suspended matter. During the periods of high turbidity the suspended matter probably consists largely of finely divided clay and silt from surface erosion and scouring of the river channel. This material, being more or less similar in average fineness and other physical properties to the silica used in making up the turbidity standard, gives a coefficient of fineness approximating unity. Along with this material there is, however, at all times, a certain amount of organic matter, living plankton, and organic débris, radically different in physical properties from the inorganic soil particles. This organic matter, being of lower specific gravity than soil particles, presumably does not settle as readily as do the latter, so that in periods of low velocity the proportion of organic matter is increased, perhaps also its amount may be absolutely increased by the establishment of conditions more favorable for plankton life. Whatever the explanation, it appears from these observations that in the Ohio River at Cincinnati turbidity is a fair index of the weight of suspended matter in periods of high turbidity, but not in periods when the turbidity is exceptionally low.

As determinations of the weights of suspended matter were not included in our schedule of examinations, no data were collected during 1914 and 1915 relative to the coefficient of fineness; but

during February and March, 1916, Mr. C. C. Fishburne, a student at the University of Cincinnati, working in our laboratory, made determinations of turbidities and weights of suspended matter upon 83 samples collected from the Ohio at stations 475, 488, and 492, below Cincinnati. His results may be summarized as follows:

	Mean	Median	Maximum	Minimum
Turbidity	259	160	1,833	60
Suspended matter, parts per million	293	204	2,060	74
Coefficient of fineness	1.13	1.13	1.77	[1] .80

[1] Exclusive of three observations giving extremely low coefficients of fineness, apparently due to errors in determination.

These observations are in accord with the general conclusions indicated by the more extensive studies by Ellms, previously quoted, namely, that in the waters of the Ohio River turbidity, within ranges above about 50 parts per million, is a satisfactory index of the weight of suspended matter, which presumably consists cheifly of inorganic particles from soil erosion.

Comparative turbidity of the Ohio and other rivers.—The average turbidities of the Ohio River above Cincinnati and above Louisville [10] for the three full years, 1914, 1915, and 1916, are shown in Table No. 60, together with comparable data for several other streams in various parts of the United States. As shown by this comparison, the Ohio in the Cincinnati-Louisville zone is of rather high turbidity, much higher than the streams of the northeastern section of the country, but less turbid than the lower Mississippi, and far less than the Missouri, the Rio Grande, and other characteristically muddy streams farther west and south. The tributaries which enter the Ohio in this zone are all of somewhat higher turbidity than the main stream.

TABLE No. 60.—*Average turbidities of various rivers in the United States as compared with the Ohio*

River	Sampling station	Mean turbidity	Years of observation	Authority
Merrimac	Lawrence, Mass	[a] 7.5	1908–1914	Clark. [b]
Delaware	Torresdale, Pa	29	1913	West. [c]
Allegheny	Pittsburgh, Pa	57	6 years	Drake. [b]
Scioto	Columbus, Ohio	69	1913–1914	Hoover. [b]
Potomac	Great Falls, Md	119	1906–1914	Hardy. [b]
Ohio	Cincinnati, Ohio	192	1908–1914	Ellms. [2]
Ohio (sta. 461)	do	158	1914–1916	Original data, PHS.
Ohio (sta. 598)	Louisville, Ky	171	1914–1916	Do.
Mississippi	New Orleans, La	600	1909–1913	Earl. [b]
Do	St. Louis, Mo	1,340	1906–1913	Wall. [b]
Missouri	Kansas City, Kans	1,909		U. S. Geological Survey. [d]
Rio Grande	Laredo, Tex	2,475		Do. [d]

[a] Apparently refers to weight of suspended matter and not turbidity. While the table from which the data quoted from Flinn, Weston, and Bogert are taken is entitled "Quantity of Solids Carried in Suspension, etc.," the annotations indicate that the other figures cited here refer to turbidities.
[b] Quoted by Flinn, Weston, and Bogert—Waterworks Handbook, New York ,1918, McGraw-Hill Company, 1st ed., p. 49.
[c] Ibid. p. 665.
[d] Ibid. p. 669.
[10] These sampling stations, Nos. 461 and 598, are on sections corresponding respectively to the intakes of the Cincinnati and Louisville water supplies.

Variations in turbidity, monthly means.—While the mean turbidity over a long period, of a year or more, affords a convenient basis for comparison, more importance, for most purposes, is attached to the variations as shown by monthly averages, or even by daily observations. The monthly means of turbidity readings at the principal sampling stations maintained on the Ohio River and its tributaries during the period January 1 to October 15, 1914, are summarized in Table No. 61, following. At all sampling stations the turbidity varied widely within this period, tending generally to be high during the high-water months, January to May, and quite low during the months of low water, June to October. However, during the period of generally low water, high turbidities were observed in certain months upon all the tributaries except the Beaver and the Tennessee, and at all Ohio River sampling stations below the Wheeling district. These high turbidities represent the effect of summer rains, which characteristically cause excessive turbidity for short periods, usually of a few days or even less; and monthly means fail to show the true range of variation.

TABLE No. 61.—*Turbidities of samples from principal sampling stations on the Ohio River and its tributaries, January 1–October 15, 1914*

[Means for each month and for designated seasonal periods]

Sampling station	Mean turbidity, silica scale												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct. 1 to 15	Averages		
											Jan. to Mar.	Apr. and May	June to Oct.
Ohio:													
5 and 11 [1]	86	78	61	60	62	52	4	4	10	8	75	61	16
65	------	------	------	------	82	21	6	4	33	5	------	------	14
88	------	------	------	------	96	30	11	13	25	8	------	------	17
104	------	------	------	------	73	49	7	26	23	9	------	------	23
348	60	121	115	158	152	30	100	90	80	21	99	155	64
358	69	174	130	163	157	34	79	118	89	24	124	160	69
461	95	208	155	187	138	12	22	145	153	24	153	162	71
475	106	245	174	171	160	127	25	199	94	28	175	166	95
482	97	250	176	160	174	102	23	173	84	25	174	167	81
488	------	------	------	129	172	63	26	125	86	27	------	150	65
492	------	------	------	148	186	47	95	130	92	25	------	167	78
543	------	------	------	------	------	------	------	------	116	7	------	------	------
598	76	435	252	167	145	60	7	24	118	6	254	156	43
619	[2] 98	[2] 400	285	220	179	71	14	28	119	10	261	200	48
904	------	------	------	------	211	62	15	18	150	91	------	------	67
920	------	------	------	------	198	46	87	41	186	122	------	------	96
933	------	------	------	------	195	37	72	39	169	106	------	------	85
Allegheny River [3]	62	71	71	50	11	20	16	15	18	16	68	30	17
Monongahela River [4]	85	62	55	53	12	12	8	4	5	11	67	32	8
Beaver River	------	------	------	93	85	26	11	17	17	15	------	89	17
Scioto River	41	217	208	128	158	91	64	174	97	49	155	143	95
Little Miami River	171	218	225	161	193	78	272	333	49	17	205	177	149
Licking River	189	381	215	188	206	391	63	458	340	178	262	197	286
Miami River	------	------	------	78	109	74	233	565	72	54	------	94	200
Kentucky River	------	------	------	------	------	------	------	------	132	14	------	------	------
Cumberland River	------	------	------	------	235	50	269	123	238	285	------	------	193
Tennessee River	------	------	------	------	85	82	90	60	98	82	------	------	82

NOTE.—The turbidities given in this table are means of determinations made upon bacteriological samples collected three to six days weekly, and do not correspond precisely to the data given in Table 50.

[1] Samples from station 5, during January, February, and August; from station 11 other months.
[2] Samples from station 611, January and February.
[3] Samples from station A-1, January–March; thereafter from station A-7.
[4] Samples from station M-1, January–March; thereafter from station M-12.

In general, the turbidity of the Ohio tends to increase as the water passes downstream, due to the fact that the tributaries which it receives below Pittsburgh are characteristically more turbid than its headwaters. During each month of the period, the Ohio reached its maximum turbidity at or below Cincinnati, usually at or below Louisville.

Observations throughout the years 1914, 1915, and 1916, at stations on the main stream from Cincinnati to Louisville, and on tributaries entering this stretch, are summarized in Table No. 62. As was the case during the briefer period covered in the preceding table, the tributaries show, on an average, higher turbidities than the main stream, with the result that the turbidity at station 598, above Louisville, averages, for each year, higher than at station 461, above Cincinnati. However, considering individual months, the turbidity between stations 461 and 598 shows a decrease somewhat more frequently than an increase, notwithstanding that almost without exception the intervening tributaries tend toward an increase of turbidity. This decrease, where it exceeds the probable error of the observations, is, therefore, obviously the effect of sedimentation. This effect is more or less counterbalanced over any long period by the scouring up of sediment from the river bottom during periods of higher stream velocity. Actually, the effect of scour does not quite balance that of sedimentation when results are expressed in degrees of turbidity, as shown by the fact that for yearly or longer periods the average turbidity at station 598 is slightly lower than at station 492 (located below the Little Miami, Licking, and Miami Rivers) although the Kentucky River which intervenes is of higher turbidity than the Ohio at station 492. However, it is evident that an exact balance is not to be expected, even though all the suspended matter deposited upon the river bottom be subsequently scoured up, for sedimentation occurs at periods of low velocities with relatively low discharge, and scour occurs at higher velocities with greater discharge. Therefore, the same mass of material when scoured up is suspended in a larger volume of water, and does not cause a proportionate increase in degrees of turbidity. An exact balance is to be expected only when the amount of suspended matter is calculated on the basis of turbidity and volume, and upon such a basis of calculation the mean annual weight of suspended matter carried at station 598 corresponds within 4 per cent to the amount carried by the Ohio at station 492 plus that carried by the Kentucky.

TABLE No. 62.—*Turbidities of samples from principal sampling stations on the Ohio River and tributaries, Cincinnati to Louisville*

[Monthly means, 1914, 1915, and 1916]

Month	Ohio, 461 (1)	Little Miami (2)	Licking (3)	Ohio, 475 (4)	Ohio, 482 (5)	Ohio, 488 (6)	Miami (7)	Ohio, 492 (8)	Ohio, 543 (9)	Kentucky (10)	Ohio, 598 (11)
1914											
January	95	171	189	106	97	------	------	------	------	------	76
February	208	218	381	245	250	------	------	------	------	------	435
March	155	225	215	174	176	------	------	------	------	------	252
April	187	161	188	171	160	129	78	146	------	------	167
May	138	193	206	160	174	172	109	186	------	------	145
June	12	78	391	127	102	63	74	47	------	------	60
July	22	272	63	25	23	26	233	95	------	------	7
August	145	333	458	199	173	125	565	130	------	------	24
September	153	44	340	94	84	86	72	92	116	132	118
October	109	89	201	163	100	121	63	172	98	163	73
November	14	14	42	17	16	13	23	12	16	37	11
December	283	108	275	337	369	323	37	301	288	337	214
1915											
January	213	345	299	244	258	268	196	266	206	240	267
February	151	106	124	143	152	138	124	143	189	210	256
March	80	31	148	90	87	93	39	82	104	94	86
April	24	47	161	26	27	26	41	28	16	28	12
May	45	724	1,760	324	276	310	129	328	236	88	171
June	281	311	1,450	413	427	430	446	387	374	477	246
July	369	657	982	642	605	632	992	751	410	968	314
August	172	576	660	273	280	261	444	332	257	357	157
September	160	193	206	174	177	163	145	185	201	254	114
October	167	136	124	169	174	164	118	175	153	197	146
November	89	71	135	96	92	93	44	79	115	173	118
December	182	70	255	211	210	198	153	198	178	319	293
1916											
January	235	328	477	277	288	284	432	315	364	599	364
February	207	114	300	234	238	240	167	257	249	212	332
March	329	495	448	397	391	429	337	411	276	232	451
April	107	64	72	105	107	107	206	118	92	95	151
May	123	114	121	146	137	139	205	163	104	25	130
June	306	242	485	339	357	326	323	321	340	274	357
July	183	163	95	222	220	227	97	209	103	151	88
August	506	295	895	503	453	363	438	361	232	305	216
September	38	195	481	65	47	43	71	48	29	124	24
October	51	32	243	78	79	73	12	69	32	43	33
November	19	24	99	18	16	16	11	16	18	27	18
December	118	193	428	153	158	174	49	160	127	357	235
Average:											
1914	127	159	246	152	144	------	------	------	------	------	132
1915	161	272	525	234	230	231	239	246	203	284	182
1916	185	188	345	211	208	202	196	204	164	204	200

Variations in turbidity by days.—Monthly mean turbidities, though significant and convenient for many purposes, give little idea of the variations in turbidity encountered from day to day, as in the operation of filtration plants. The distribution of turbidities of individual samples from stations 461 and 598, and from the Little Miami and Licking Rivers, is shown in Table No. 63, the grouping being similar to that commonly used, following the recommendations of the New England Waterworks Association.

TABLE NO. 63.—*Distribution of turbidities of individual samples from the Ohio River at Cincinnati, and at Louisville, and from the Little Miami and Licking Rivers, 1914, 1915, 1916*

Turbidity range	Number of observations				Per cent of observations			
	Ohio, station 461	Ohio, station 598	Little Miami	Licking	Ohio, station 461	Ohio, station 598	Little Miami	Licking
0–25	120	207	118	53	18.0	27.0	28.6	7.5
26–50	76	69	88	125	11.3	9.1	21.3	17.7
51–100	115	115	55	146	17.2	15.0	13.3	20.7
101–250	212	210	70	164	31.6	27.4	16.9	23.3
251–500	113	115	40	93	16.9	15.0	9.7	13.2
501–1,000	29	40	30	64	4.3	5.2	7.3	9.1
1,001–2,500	4	10	8	44	.6	1.3	1.9	6.2
2,501–5,000	1	0	4	12	.1	.0	1.0	1.7
5,001–10,000	0	0	0	4	.0	.0	.0	.6
Total	670	766	413	705	100	100	100	100

At all four stations turbidities below the mean are much more frequent than those above, and turbidities within the lowest range are considerably more frequent than is indicated by the monthly means. Although the mean turbidity at station 598 is higher than at station 461, turbidities of the lowest range (under 25) are much more frequent at the former station, the higher average turbidity being due to the more frequent but still relatively rare occurrence of excessively high turbidities, over 500 parts per million. Similarly, in the Little Miami River, which is of higher mean turbidity than either of the Ohio River sections, the most frequent range of turbidity is under 25 parts per million. The Little Miami and Licking, as would be expected because of their smaller watersheds, show wider ranges of variation in turbidity than do the Ohio River sections.

Variations in turbidity in relation to velocity. The phenomena of sedimentation and scour, as evidenced by decrease and increase, respectively, of turbidity in a stretch of river which receives no significant inflow, are of some interest in relation to the decrease in numbers of bacteria which characteristically takes place in such stretches. Presumably physical removal by sedimentation is a factor in this bacterial decrease, but the removal of bacteria due to this cause can not be separated directly from decrease due to death of those remaining in suspension. Also, it is not to be expected that with respect to bacteria the numbers lost by sedimentation will be balanced by the numbers added as the result of channel scouring, since bacteria deposited upon the bottom are not a fixed quantity. Quite certainly, while on the bottom, they are undergoing some change, which theoretically may be in the direction either of an increase or decrease of numbers. The same considera-

tions apply also, more or less, to the relatively unstable organic matter represented by determinations of organic nitrogen and oxygen consumed. But the inorganic matter which chiefly contributes to turbidity is quite stable, so that any change in its amount within a river-stretch receiving no additional inflow may quite safely be taken as the result of scour or sedimentation. By studying these changes in relation to their governing factors some idea may be gained of the probable effect of the same factors upon the content of bacteria and of unstable organic matter.

No attempt will be made here at a detailed analysis of the forces governing the transportation and deposition of suspended matter in streams. A simple analysis suffices, however, to demonstrate that the changes in turbidity observed in stretches of the river which are relatively free from the disturbing influence of local inflow are intimately related to velocity of flow, which is recognized as one of the most important controlling factors.

The stretches of river suitable for such simple analysis are those lying between sampling stations where frequent observations were made over a considerable period of time, and which are free from any considerable disturbing influence due to inflow between the sampling stations. Stretches more or less fully answering these requirements are those lying between:

(1) Sampling stations 475 and 482; no local inflow of measurable amount in proportion to the flow of the main stream; observations at both stations throughout the years 1914, 1915, and 1916.

(2) Sampling stations 492 and 543; no intervening tributaries of importance; local inflow estimated as about 1.4 per cent of the discharge at station 492; observations at both stations from September, 1914, to December, 1916, inclusive.

(3) Sampling stations 543 and 598; no intervening tributaries of importance, except the Kentucky River, for which the observations at station 543 may be corrected; local inflow estimated at about 1.1 per cent of discharge below the Kentucky; observations at both stations from September, 1914, to December, 1916, inclusive.

(4) Sampling stations 492 and 598, with correction for discharge and turbidity of Kentucky River; without correction for additional inflow from minor tributaries, which amounts to about 2.6 per cent of the discharge at station 492.

The direction and extent of the change in turbidity between the upper and lower end of a river stretch is indicated by what may be called a "suspension ratio"—that is, the ratio of turbidity at the lower end to turbidity at the upper end. Disregarding the effect of local inflow (except in the case of the Kentucky River, for which corrections are made) the decrease or increase of turbidity indicated by the

suspension ratio may be considered as due to sedimentation or scour, respectively.[11] Monthly mean turbidities are used in computing the ratios.

The suspension ratios thus calculated for each of the designated stretches for each month during which observations were made are shown in Table No. 64, where they are arranged in order of magnitude, not in chronological order. Corresponding monthly mean velocities are shown in parallel columns.

Inspection of this table shows, first, the extent of changes in turbidity between stations where, if there were no tendency either to sedimentation or scour, the turbidity should remain approximately constant. In the short stretch 475–482, the changes range from an increase of 10 per cent to a decrease of 39 per cent at the lower station as compared with the upper.[12] In the two longer and nearly equal stretches, 492–543 and 543–598, the variation is wider, as expected, increases exceeding 25 per cent and decreases exceeding 40 per cent being not infrequent. In the longest stretch, 492–598, the range of variation is still wider, an increase of 25 per cent or more being noted in nearly one-fourth of the observations, while slightly more than one-fourth show a decrease of 50 per cent or more. In all the stretches except 475–482, a decrease in turbidity occurs more frequently than an increase, and in all stretches, without exception, the range of decrease is greater than of increase.

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[11] The error due to disregarding inflow from minor tributaries is not a compensating error. Heavy rainfall, local to the drainage area of the minor tributaries, may greatly increase their discharge in proportion to that of the main stream, at the same time increasing their turbidity. If this happens when the main stream is at low stage, with low turbidity, the inflow from a small drainage area may disproportionately increase the turbidity of the main stream. This combination of circumstances is not unusual during the summer period of low water. Local inflow would disproportionately decrease turbidity in the main stream only when conditions of high discharge and low turbidity in the minor tributaries coincided with low discharge and high turbidity in the main stream, a combination of conditions which is actually most unlikely to occur.

[12] Considered individually, variations in monthly mean turbidity within a range of ±10 per cent, with occasional wider variations are hardly significant in view of the probable error of the observations.

TABLE NO. 64.—*Monthly mean suspension ratios and velocities of flow in designated stretches of the Ohio River, 1914, 1915, and 1916.*

Stations 475–482		Stations 492–543		Stations 543–598 [1]		Stations 492–598	
Suspension ratio	Mean velocity feet per second	Suspension ratio	Mean velocity feet per second	Suspension ratio	Mean velocity feet per second	Suspension ratio	Mean velocity feet per second
1.10	2.69	1.46	2.26	1.65	4.17	1.79	4.51
1.09	3.35	1.32	4.58	1.64	4.17	1.49	1.77
1.06	3.83	1.27	2.98	1.44	3.34	1.48	3.49
1.06	4.29	1.26	1.06	1.35	4.45	1.29	4.38
1.05	3.15	1.16	4.99	1.35	4.30	1.28	1.06
1.04	1.73	1.13	1.10	1.28	4.00	1.28	.84
1.04	5.26	1.09	2.13	1.28	2.49	1.28	4.24
1.03	2.50					1.16	4.94
1.03	2.10	1.06	3.35	1.06	2.78		
		.97	2.78	1.00	.70	1.13	4.58
1.03	2.34	.97	4.45	1.00	.83	1.12	.88
1.03	2.19	.96	2.94	1.00	.74	1.11	3.03
1.02	1.88	.90	3.69	.96	4.89	1.10	4.23
1.02	4.04	.88	2.63	.94	1.63	1.05	2.52
1.02	3.96	.83	.82	.93	1.78	1.00	4.06
1.02	3.76					.92	.62
1.01	3.64	.78	2.38	.90	1.32	.83	2.11
1.01	1.00	.78	4.32	.89	2.22		
1.00	3.50	.77	4.11	.84	1.35	.80	2.77
		.72	2.32	.75	1.53	.78	3.26
1.00	1.83	.67	4.30	.74	2.16	.71	2.48
.98	3.92	.64	3.15	.73	.75	.64	2.26
.97	2.74	.64	2.02	.71	1.29	.62	1.66
.96	1.98					.61	1.95
.94	4.29	.63	2.45	.68	2.01	.60	1.59
.94	.54	.60	1.12	.67	.63	.52	1.83
.94	2.56	.57	.95	.66	1.94		
.94	2.97	.57	1.97	.65	.50	.50	.89
.92	2.98	.55	2.80	.60	1.57	.50	1.88
		.49	2.08	.56	1.38	.48	.99
.92	.79	.46	1.25	.47	1.48	.43	1.55
.90	1.78					.42	2.33
.89	.73					.42	1.63
.89	.77					.42	.75
.87	.65					.18	.76
.85	2.06					.07	.89
.80	.93						
.72	.80						
.61	.63						
QUARTILE AVERAGES							
1.06	3.21	1.24	2.73	1.43	3.85	1.39	3.15
1.02	2.92	.94	2.95	.98	1.91	1.03	2.75
.95	2.65	.71	3.23	.79	1.52	.66	2.22
.83	1.02	.55	1.80	.61	1.36	.38	1.46

[1] Observed turbidities at station 543, above the Kentucky River, corrected according to discharge and turbidity of the Kentucky River, to represent a calculated turbidity below the mouth of the Kentucky River.

Inspection of the table, especially of the quartile averages, shows further, with respect to all the stretches except that from 492–543, a very definite positive correlation between suspension ratios and mean velocities. The coefficients of correlation computed from the data given in the table are:

River stretch	Coefficient of correlation, suspension ratio with velocity
475–482	+.55±.078
492–543	+.24±.120
543–598	+.72±.061
492–598	+.57±.079

These coefficients, in relation to their probable errors, are sufficiently high to be unmistakably significant except in the case of the stretch 492–543, where the correlation is hardly significant unless taken in connection with that shown in other stretches. It is not apparent why the correlation should be so much lower in the stretch 492–543 than in the stretch 543–598, which is of about the same length, unless it be, perhaps, that observations at station 492 are subject to some very considerable sampling error. As it is obvious that the relation between suspension ratio and velocity is not one of direct proportionate variation, that is, not a straight-line relation, it is not expressed best by the coefficient of correlation, which serves, however, to demonstrate that changes in turbidity between consecutive sampling stations with little tributary inflow are related in an intimate and orderly way to variations in stream velocity.

As to the significance of these studies in relation to bacteria and organic suspended matter, it can not be assumed, without further evidence, that the changes in bacterial numbers due to sedimentation and scour are directly proportionate to the change in turbidity. It may be inferred, however, that changes in turbidity indicate the direction of coincident change in bacterial content due to the same physical forces, and that they indicate roughly the probable extent of bacterial decrease attributable to simple sedimentation in these and comparable stretches. Without a knowledge of the fate of bacteria deposited upon the river bottom, these studies warrant no inference as to the effect of channel scouring upon bacterial content of the water.

Turbidity as related to rainfall and run-off.—The factors other than sedimentation and scouring of the river bottom which determine variations in turbidity are quite complex, having to do with the extent of soil erosion. The determinable factors of most obvious influence upon turbidity are run-off (i. e. discharge, of which river stage is a function) and rainfall. The relation of these factors to turbidity is shown in Table No. 65 for station 461 on the Ohio and for the Little Miami and Licking Rivers, for the years 1914 and 1915, monthly mean turbidities being related to total monthly rainfall and run-off on the watershed above each station. Inspection of this table shows that on all four streams the turbidity increases with rainfall in a very regular manner. Turbidity and run-off do not appear, on inspection, to be correlated, except in the case of the Little Miami River, where there is a rather striking negative correlation, turbidity decreasing as run-off increases.

TABLE No. 65.—*Relation between turbidity, rainfall, and run-off in the Ohio River and tributaries in Cincinnati district, by months, 1914 and 1915*

Ohio River, station 461			Little Miami			Licking River			Miami River		
Turbidity	Rain-fall (inches)	Run-off (inches)	Tur-bidity	Rain-fall (inches)	Run-off (inches)	Tur-bidity	Rain-fall (inches)	Run-off (inches)	Tur-bidity	Rain-fall (inches)	Run-off (inches)
369	5. 60	0. 93	724	5. 83	0. 42	1, 760	6. 23	1. 24	992	6. 46	2. 01
283	4. 72	1. 14	657	4. 90	1. 06	1, 450	4. 66	1. 09	565	4. 98	. 24
281	4. 14	. 98	576	3. 83	1. 42	982	5. 79	2. 03	446	3. 95	. 78
213	4. 38	2. 42	345	3. 58	1. 79	660	5. 68	. 71	444	5. 77	1. 01
208	3. 44	2. 20	333	5. 68	. 13	458	6. 18	. 20	233	2. 66	. 18
187	4. 23	3. 34	311	4. 06	. 87	391	2. 47	. 28	196	3. 25	. 72
Av. 257	4. 42	1. 83	491	4. 65	. 95	950	5. 17	. 93	479	4. 51	. 82
182	4. 50	1. 76	272	4. 90	. 13	381	4. 34	3. 63	154	4. 05	1. 22
172	4. 73	. 71	225	2. 32	3. 76	340	1. 60	. 06	145	4. 54	1. 19
167	3. 00	. 93	218	3. 78	2. 28	299	3. 84	2. 55	129	4. 65	. 52
160	3. 82	. 68	193	1. 65	1. 26	275	4. 21	1. 68	124	1. 44	3. 30
155	3. 00	2. 08	193	5. 27	1. 73	255	6. 10	4. 63	118	2. 29	. 86
153	1. 53	. 24	171	2. 33	. 97	215	2. 66	1. 88	--------	--------	--------
Av. 165	3. 43	1. 07	212	3. 38	1. 69	294	3. 79	2. 41	134	3. 39	1. 42
151	2. 60	3. 14	161	3. 09	3. 42	206	2. 34	1. 10	109	2. 05	. 82
145	4. 98	. 20	136	2. 70	. 91	206	3. 43	. 35	78	3. 56	2. 65
138	2. 66	1. 69	108	3. 48	. 71	201	4. 21	. 99	74	2. 88	. 23
109	3. 27	. 18	106	1. 44	7. 39	189	2. 33	. 93	72	1. 33	. 16
95	2. 80	1. 34	89	3. 70	. 43	188	2. 81	1. 56	63	3. 17	. 23
89	2. 94	. 75	78	2. 23	. 12	161	1. 11	. 39	--------	--------	--------
Av. 121	3. 21	1. 22	113	2. 77	2. 16	192	2. 71	. 89	79	2. 60	. 82
80	1. 72	1. 13	71	2. 63	. 60	148	2. 11	1. 16	44	2. 39	. 63
45	4. 30	. 72	70	4. 25	4. 93	135	3. 30	1. 22	41	1. 81	. 35
24	1. 61	. 56	47	1. 37	. 19	124	2. 76	. 79	39	1. 44	. 56
22	3. 21	. 26	44	. 97	. 10	124	1. 51	2. 92	37	3. 20	. 40
14	3. 05	. 28	31	1. 50	. 43	63	3. 11	. 03	23	1. 32	. 14
12	1. 60	. 16	14	1. 33	. 10	42	1. 35	. 06	--------	--------	--------
Av. 33	2. 58	. 52	46	2. 01	1. 06	106	2. 36	1. 03	37	2. 03	. 42

NOTE.—Turbidities are monthly means, 1914 and 1915, arrayed in order of decreasing magnitude. Rainfall and run-off are computed totals for the watershed for months corresponding in each instance to turbidities designated.

The coefficients of correlation of turbidity with rainfall and run-off, respectively, as computed from the data shown in this table, are:

Coefficients of correlation

Rivers	Turbidity with Run-off	Turbidity with rainfall
Ohio, station 461	+0. 366±0. 119	+0. 648±0. 080
Little Miami	− . 089± . 137	+ . 676± . 075
Licking	+ . 029± . 138	+ . 619± . 085
Miami	+ . 225± . 140	+ . 761± . 062

From the above it is evident that in all four streams there is a significant positive correlation between rainfall and turbidity, while the correlation with run-off gives coefficients which vary in sign, and are certainly insignificant in two, probably in all four cases.

2. Hardness and Alkalinity

The hardness and alkalinity of river waters, although they are characteristics of real importance from the economic point of view, are of relatively little significance from the standpoint of this study, because they are due to comparatively inert mineral salts which, in moderate amounts, have no demonstrated direct effect upon health; also because they are, for the most part, fixed characteristics of the water, subject to more or less modification by artificial treatment, but not preventable. To the above statement an exception must be made with respect to the conditions of excessive hardness and reduced alkalinity or even acidity prevailing in the upper Ohio, Allegheny, and Monongahela Rivers, since these conditions, being due to acid wastes from the mining and iron industries, are at least partially preventable, and since they exert a marked influence upon the biology of the rivers. This, however, is a special case, to be considered separately.

The monthly means of hardness and alkalinity at all stations on the Ohio River where these determinations were made from January to October, 1914, are shown in Table No. 66. According to the usual interpretation, the difference between total hardness and alkalinity, both being expressed in terms of equivalents of $CaCO_3$, represents the so-called "incrustant" or "noncarbonate" hardness, which is of special importance as causing a deposit of "hard scale" in boilers.

Table No. 66.—*Monthly means of hardness and alkalinity in samples from the Ohio River and tributaries, January 1 to October 15, 1914*

Sampling stations	January		February		March		April		May	
	Hardness	Alkalinity	Hardness	Alkalinity	Hardness	Alkalinity	Hardness	Alkalinity	Hardness	Alkalinity
Ohio:										
5–11	47	5	36	7	66	8	47	4	49	9
65	--------	--------	--------	--------	--------	--------	--------	--------	55	16
88	--------	--------	--------	--------	--------	--------	--------	--------	49	18
104	--------	--------	--------	--------	--------	--------	--------	--------	60	21
349	61	22	47	18	60	21	50	16	57	25
358	63	22	54	18	64	24	49	19	68	33
461	63	29	57	29	74	31	52	28	62	32
482	66	31	60	28	66	31	57	23	55	37
598	80	43	99	65	74	49	78	41	60	42
904	--------	--------	--------	--------	--------	--------	--------	--------	94	65
933	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Allegheny River	47	13	35	--------	61	11	39	11	44	18
Monongahela	84	−18	60	−2	69	3	47	5	129	14
Beaver	--------	--------	--------	--------	--------	--------	65	11	75	31
Scioto	201	153	158	112	103	88	179	132	166	151
Little Miami	237	179	170	130	153	123	228	169	215	182
Licking	126	100	99	84	106	77	89	79	75	72
Miami	--------	--------	--------	--------	--------	--------	191	196	243	207
Cumberland	--------	--------	--------	--------	--------	--------	--------	--------	70	68
Tennessee	--------	--------	--------	--------	--------	--------	--------	--------	60	50

95404°—24†——12

TABLE No. 66.—*Monthly means of hardness and alkalinity in samples from the Ohio River and tributaries, January 1 to October 15, 1914*—Continued

Sampling stations	June		July		August		September		October 1-15	
	Hardness	Alkalinity	Hardness	Alkalinity	Hardness	Alkalinity	Hardness	Alkalinity	Hardness	Alkalinity
Ohio:										
5-11	91	8	115	5	139	3	120	17	156	21
65	81	14	120	7	136	9	120	16	122	22
88	100	12	121	7	139	7	139	7	127	11
104	94	14	119	8	130	5	144	9	--------	--------
349	97	44	95	38	110	39	125	37	110	46
358	111	64	133	57	122	60	142	56	135	78
461	103	59	105	55	102	42	128	47	[1] 122	[1] 69
482	114	65	138	58	124	63	130	53	[1] 120	[1] 69
598	109	73	155	74	119	73	132	62	[1] 128	[1] 83
904	140	104	164	122	146	103	128	89	130	104
933	--------	--------	--------	--------	108	84	115	81	108	89
Allegheny River	44	18	89	16	128	9	98	25	138	17
Monongahela	146	−20	121	−6	138	−16	175	−16	231	−15
Beaver	114	42	153	37	222	25	210	31	224	26
Scioto	166	215	152	189	209	184	232	191	255	222
Little Miami	--------	--------	--------	--------	165	153	205	181	--------	--------
Licking	91	81	100	88	92	85	--------	90	[1] 92	[1] 89
Miami	--------	--------	--------	--------	202	152	240	215	--------	--------
Cumberland	83	87	92	89	78	80	85	78	78	72
Tennessee	92	89	92	89	60	50	68	61	92	66

Both alkalinity and hardness expressed in terms of equivalent weights of $CaCO_3$. Hardness determined by soap method, January to July, inclusive. Thereafter by soda reagent method, which has been found to give results generally about 10 to 20 per cent higher.

[1] Means for whole month of October.

Total hardness.—During the months of comparatively high discharge, from January to May, the total hardness of the Ohio tended rather constantly to increase in passage downstream, varying between 36 and 66 parts per million at stations 5 and 11, immediately below Pittsburgh, and increasing to a range between 60 and 100 parts per million at station 598, above Louisville.

During the period of low water, from June to October, the hardness of the Ohio was increased at all stations, the increase being proportionately greatest in the upper river, so that the increase in passage downstream was less consistent and less marked than in months of higher run-off.

The Beaver, Scioto, Little Miami, and Miami Rivers all show considerably higher hardness than the Ohio at their respective junctions; the hardness of the Licking River being sometimes greater and sometimes less than that of the Ohio at station 461; and the hardness of the Cumberland and Tennessee Rivers consistently less than that of the Ohio above their mouths.

Alkalinity.—Alkalinity shows similar variations, namely an increase throughout the river in low-water as compared with high-water periods, and an increase in passage downstream which is more consistent and of wider range than the similar increase in hardness. During 7 of the 10 months of observation the waters of the Monongahela showed no alkalinity, reacting acid to methyl orange; and during the other 3 months (March, April, and May) the alkalinity

was very low. The waters of the Allegheny, though not showing the presence of free acid, were consistently of low alkalinity, from 10 to 20 parts per million, and in consequence the waters of the upper Ohio (above Wheeling), made up almost wholly of the discharge of these two rivers, were likewise of extremely low alkalinity—at times actually acid for periods of a few days, though this is not shown in the monthly means. These conditions are undoubtedly artificial, resulting from the excessive discharge of acid wastes from coal mines and pickling liquors from iron mills. The natural alkalinity of the Beaver is also probably reduced to a measurable extent by acid wastes, chiefly from iron and steel mills. All the tributaries observed, from the Beaver to the Miami, inclusive, show higher alkalinities than the main stream, while the Tennessee and Cumberland show less.

Noncarbonate hardness.—The noncarbonate or incrustant hardness, which is quite high in the Allegheny, Monongahela, and Beaver Rivers, and in the Ohio from Pittsburgh to Wheeling, is rapidly reduced by the inflow of tributaries, reaching a minimum below the Tennessee. The varying character of the run-off from different portions of the Ohio watershed with respect to alkalinity and incrustant hardness is shown in Table No. 67, which shows, for the drainage areas between successive points on the river, the estimated contribution of alkalinity and incrustant (noncarbonate) hardness in kilograms per square mile per day during the high-water period March to May and the low-water period June to October, 1914.

TABLE No. 67.—*Average amounts of alkalinity and incrustant hardness, in kilograms per square mile of intermediate drainage area, contributed to Ohio River in various successive stretches during high and low water periods of 1914*

Stations	Intermediate drainage area	Kilograms per square mile daily in terms of $CaCO_3$			
		March–May, 1914 (high water)		June–October 1914 (low water)	
		Aklalinity	Incrustant hardness	Alkalinity	Incrustant hardness
	Sq. miles				
Above No. 11	19,310	52	366	9	77
11 to 104	5,670	----------	----------	2	30
104 to 349	37,340	[1] 195	[1] 71	27	19
349 to 482	14,000	350	50	88	19
482 to 598	14,870	397	108	64	19
598 to 904	52,810	----------	----------	91	7
904 to 933	58,700	----------	----------	59	4

[1] Stations 11 to 349.

General characterization.—In general, the waters of the Ohio River and its major tributaries may be classed as of moderate hardness, such that they do not ordinarily require artificial softening to render them fit for domestic use and use in boilers. The incrustant hardness

and corrosive constituents in the upper river, and more particularly in the Monongahela are, however, sufficient to cause serious trouble, and moreover these conditions are becoming more aggravated as the acid-waste pollution upon the watershed of the upper river increases.

Comparison with other streams.—The average hardness (by the soap method) and the alkalinity of the Ohio River above the cities of Cincinnati and Louisville, together with comparable data for other streams in various sections of the United States, are grouped in Table No. 68.

TABLE No. 68.—*Hardness and alkalinity of waters of various rivers in United States* [1] *as compared with the Ohio*

River	Place	Parts per million of—	
		Hardness, by soap	Alkalinity
Kennebec	Augusta, Me.	19.1	15.3
Merrimac	Lawrence, Mass.	11.0	
Connecticut	Middletown, Conn.	32	
Hudson	Albany, N. Y.	67	
Delaware	Philadelphia	47.6	27.2
Allegheny	Pittsburgh	48	19
Ohio	Cincinnati	[2] 69	[3] 45
Do	Louisville	[2] 83	[3] 63
Mississippi	Minneapolis	164	150
Do	New Orleans	84	75

[1] Rearranged from Flinn, Weston & Bogert, Waterworks Handbook, New York, McGraw-Hill, 1918. 1st. ed., p. 668, except data for Ohio River.
[2] Average of 6 determinations Jan.-June, 1914.
[3] Average of years 1914 and 1915.

In the Cincinnati-Louisville zone the water of the Ohio River shows a greater hardness and higher alkalinity than the waters of the North and Middle Atlantic States. It is comparable to the water of the Mississippi River at its mouth, but carries considerably less hardness and is lower in alkalinity than the waters of the northern section of the Mississippi drainage area. The Little Miami and Licking Rivers, which enter the Ohio in this zone, are higher in hardness and alkalinity than the main stream.

INFLUENCE OF ACID WASTES IN THE MONONGAHELA, ALLEGHENY, AND UPPER OHIO.

The differences in alkalinity and hardness of waters from various portions of the watershed of the Ohio are, for the most part, attributable to natural differences in the geology of the drainage areas, but in the drainage area of the upper Ohio, and more especially that of the Monongahela, the natural alkalinity of the run-off has been profoundly modified by acid wastes incident to the development of coal mining and of steel industries.

Sources and effects.—Acid wastes result from coal mining when sulphides of iron, exposed in the mining operations, become oxidized

to sulphates, and on subsequent leaching are carried away in the drainage as acid solutions of ferrous salts. In the steel industry, large quantities of sulphuric acid and, more rarely, of hydrochloric acid, are used for "pickling"; and the spent pickling liquors containing ferrous sulphate or chloride, with from one to three per cent of free acid, are usually discharged as waste, although in some plants ferrous sulphate is recovered as a by-product.

The free acid and iron salts contained in these wastes, whether derived from mine drainage or from pickling liquors, combine with the alkaline carbonates naturally present in the receiving waters, forming sulphates of calcium and magnesium, and, when present in sufficient quantity, leaving a residuum of unneutralized acid. The combination of alkaline carbonates and acid salts results in the formation of flocculent precipitates of iron compounds, with a resultant clarification of muddy waters which is very noticeable.

Chief among the harmful effects of such acid pollution are increase in permanent hardness of the river waters, and, where the acidity is not fully neutralized, the corrosion of iron and steel in boilers, in the hulls of vessels, and in submerged structures in dams. In the Monongahela and upper Ohio this corrosive effect is a matter of serious economic importance.[13] The most striking biological effects of the acid pollution as observed in the Pittsburgh district in the course of this study are a reduction or elimination of certain forms of plankton,[14] and an enormous reduction in sewage bacteria, to numbers far below what would be expected in waters subject to such heavy sewage pollution. This reduction in bacterial pollution, which is more fully discussed in Section VI of this report, is probably due in part to physical removal by coagulation and sedimentation, but also in part, and perhaps more largely, to direct inhibitory and bactericidal action. Whatever its mechanism, the effect is so great as to be a major factor in reducing the bacterial pollution of the upper river and to raise the question whether it may not offset the economic damage due to increased hardness and corrosiveness of the waters.

Character and results of analyses.—In view of the very great economic and sanitary importance which must be attached to the present and future acid pollution of the Ohio River in the vicinity of Pittsburgh, it is unfortunate that the observations made in the course of this study were not more extensive and elaborate. However, it was impossible to add to the already heavy schedule of laboratory work by undertaking elaborate or extensive studies of

[13] Roberts, T. P., "Acids in the Monongahela River," Proc. of the Eng. Soc. of Western Pa., vol. 27, No. 8, pp. 384–391.

[14] Studies of the Pollution and Natural Purification of the Ohio River, I, the Plankton and Related Organisms, Pub. Health Bull. No. 131, U. S. Pub. Health Service, 1923, pp. 24–33.

this special problem, and the observations which were made relative to the acid pollution in this region were necessarily limited to such as could be made with simple equipment and technique, and as could be combined with the schedule of other necessary studies.

With respect to hardness, no special observations were made, and the data are limited to those previously shown in the basic tables of this section and summarized above in Table No. 66. These, however, are sufficient to indicate that the permanent hardness in this zone was far in excess of that observed in any other part of the river system.

With respect to alkalinity the only determinations made up to May 20, 1914, were those which were made at all other sampling stations, as likewise shown in Table No. 66, viz, titrations in the presence of methyl orange as the indicator, using N/50 sulphuric acid in the case of alkaline and N/50 sodium carbonate in the case of acid samples. As methyl orange reacts acid to mineral acids but not to their acid salts, these titrations afford a measure of acidity only as due to free mineral acid. These tests were moreover made quite infrequently prior to May 20, using the samples collected for sanitary chemical analysis. (See Table No. 50.) From May 20 to October 15, 1914, daily titrations were made with methyl orange and with phenolphthalein, cold and at boiling temperature, using portions of the samples collected for bacteriological examinations. In samples acid to methyl orange these three titrations as ordinarily interpreted [15] would have the following significance:

1. Titrations with phenolphthalein, cold = total acidity due to free mineral acids, acid salts, and CO_2.
2. Titration with phenolphthalein, hot = acidity due to free mineral acids and acid salts.
3. Titration with methyl orange = acidity due to free mineral acids.
4. Acidity due to free CO_2 = (1) – (2).
5. Acidity due to acid salts = (2) – (3).

It should be noted, however, that the measurement of free CO_2 as the difference between (1) and (2) is not reliable without corrections which can not be made from the data at hand; and that the measure of "acid salts" as the difference between (2) and (3) is not exact.

In the case of samples reacting alkaline to methyl orange the titrations with phenolphthalein, hot and cold, add little if anything to the significance of the methyl orange titration, except to indicate the consistent absence of normal carbonates, which, except in the case of the Beaver River, might readily have been inferred from the reduced alkalinity of the samples.

[15] Standard Methods for the Examination of Water and Sewage. American Pub. Health Assoc., ed. of 1920, pp. 40–41.

Table No. 69 summarizes, as monthly averages, the results of the tests of samples collected daily from May 20 to October 15, 1914, from the Allegheny and Monongahela Rivers, from sampling stations Nos. 11, 65, and 88,[16] on the Ohio River, and from the Beaver River, which joins the Ohio between sections 11 and 65. As regards the samples reacting alkaline to methyl orange, the only data in this table which are of clear significance are the results of titrations in the presence of methyl orange; but as regards the acid samples from the Monongahela, the data may be converted into terms of free mineral acid and acid salts, as in Table No. 70, which follows:

Table No. 69.—*Summary of alkalinity determinations in Monongahela, Allegheny, Ohio, and Beaver Rivers*

[Monthly means, May-October, 1914]

[Results in parts per million, in terms of $CaCO_3$][1]

Month of—	Monongahela			Allegheny			Ohio station 11		
	Methyl orange	Phenolphthalein		Methyl orange	Phenolphthalein		Methyl orange	Phenolphthalein	
		Hot	Cold		Hot	Cold		Hot	Cold
May	−9	−49	−50	14	−0.7	−2	7	−3	−4
June	−21	−93	−107	19	+0.8	−8	9	−5	−12
July	−10	−54	−59	17	+0.2	−10	7	−6	−15
August	−14	−63	−74	19	−1.0	−12	7	−10	−23
September	−15	−67	−86	29	+3.7	−9	21	+1	−12
October	−15	−92	−104	25	−2.4	−15	29	+1	−18

Month of—	Beaver			Ohio station 65			Ohio station 88		
	Methyl orange	Phenolphthalein		Methyl orange	Phenolphthalein		Methyl orange	Phenolphthalein	
		Hot	Cold		Hot	Cold		Hot	Cold
May	28	1.4	+0.2	18	−2.0	−4.0	18	−2.0	−4.0
June	41	6.0	−6.0	16	−0.2	−5.0	16	−0.7	−6.0
July	41	8.0	−9.0	9	−1.0	−6.0	9	−2.0	−9.0
August	31	5.0	−13.0	9	−1.0	−9.0	7	−3.0	−8.0
September	39	7.0	−12.0	18	+4.0	−8.0	16	+3.0	−9.0
October	28	1.0	−18.0	24	+6.0	−7.0	18	+6.0	−11.0

[1] A negative sign (−) indicates acidity expressed in terms of $CaCO_3$.

Table No. 70.—*Concentration of free mineral acids and acid salts in the Monongahela River*

[Monthly means, May-October, 1914]

	Parts per million in terms of equivalent $CaCO_3$					
	May	June	July	August	September	October
Free acid	9	21	10	14	15	15
Acid salts	40	72	44	49	52	77

[16] The results of parallel tests at station No. 104, below Wheeling, are omitted as they do not differ significantly from those at station No. 88.

As indicated in the above tables, the waters of the Monongahela were consistently acid to methyl orange each month during the period when daily tests were made. The waters of the Allegheny always reacted alkaline to methyl orange, indicating the presence of alkaline bicarbonates, but in amounts considerably below those found in the Beaver River and other tributaries. The Ohio River at station No. 11, below the confluence of the Allegheny and Monongahela rivers, also appears to have been alkaline to methyl orange at all times if only the monthly averages presented in Table No. 69 are considered. At rare intervals, samples collected from station 11 reacted acid to methyl orange, but the acid conditions observed here never persisted more than one or two days at a time.

Reactions taking place in the streams.—As to the result to be expected when the alkaline waters of the Allegheny are mingled, in the Ohio, with the acid waters of the Monongahela, the data do not permit precise calculations, due to uncertainty concerning the reactivity of the ferrous salts. Reversible reactions of the type:

$$FeSO_4 + Ca\,(HCO_3)_2 \rightleftharpoons CaSO_4 + Fe\,(HCO_3)_2 \qquad (1)$$

are not applicable without a considerable knowledge of the extent to which they actually proceed. Moreover, even if such reactions are assumed to proceed to completion, the alkalinity of a stream as ordinarily determined by titration would not necessarily be altered by the addition of ferrous salts, since compounds of the type $Fe\,(HCO_3)_2$ may be assumed to react alkaline when titrated with sulfuric acid. The removal of such alkalinity by ferrous salts evidently depends on the removal of the iron itself from the solution. For purposes of illustration, the removal of iron salts from solution may be represented as follows:

$$Fe(HCO_3)_2 \rightleftharpoons Fe(OH)_2 + CO_2 \qquad (2)$$

or

$$Fe(HCO_3)_2 \rightleftharpoons FeCO_3 + H_2CO_3 \qquad (3)$$

The extent to which compounds of the type $Fe\,(HCO_3)_2$ are decomposed into insoluble compounds such as $Fe(OH)_2$ and $FeCO_3$ will evidently depend upon the carbon dioxide content of the water.[17] It is apparent that no decrease in volumetric alkalinity due to the further decomposition of $Fe(HCO_3)_2$ could be expected unless the insoluble compounds which resulted were actually removed from solution.

Observed versus calculated alkalinity in Ohio.—With due regard to the above indicated sources of uncertainty, it may, nevertheless be of some interest to compare observations on the Ohio at station No. 11 with computations based upon the observed acidity in the Monongahela, and the alkalinity of the Allegheny. For the purposes of this comparison the acid salts will be considered inert and only the

[17] More exactly upon the bicarbonate-ion content of the water, which in turn varies inversely as the hydrogen-ion concentration.

free mineral acid content of the Monongahela and the bicarbonate alkalinity of the Allegheny will be taken into account. Values thus computed are shown in Table No. 71 in which the amount of acid carried by the Monongahela is computed for each month in tons per day by applying the mean discharge of the river to the mean acidity in parts per million as determined by methyl-orange titrations. For convenience, these values are expressed in terms of equivalent $CaCO_3$, so that the calculated amount of bicarbonate in the Ohio will be the difference between the bicarbonate carried in the Allegheny and the acid carried in the Monongahela. These values are then compared, in Table No. 72 with the alkalinities actually observed in the Ohio at station No. 11.

TABLE No. 71.—*Amounts of free acid carried by the Monongahela and of alkalinity carried by the Allegheny and by the Ohio at station No. 11*

[Monthly means, May–October, 1914]

Month	Monongahela			Allegheny			Ohio station No. 11		
	Discharge, second-feet	Acidity as Ca Co3		Discharge, second-feet	Alkalinity as Ca Co3		Discharge, second-feet	Alkalinity as Ca Co3	
		Parts per million	Tons per day [1]		Parts per million	Tons per day [1]		Parts per million	Tons per day [1]
May [2]	9,400	9	228	32,800	14	1,238	42,200	7	797
June	2,850	21	161	6,530	19	335	9,380	9	228
July	1,920	10	52	3,460	17	159	5,380	7	102
August	2,070	14	78	1,660	19	85	3,730	7	70
September	1,120	15	45	2,250	29	176	3,370	21	191
October	830	15	34	840	25	57	1,670	29	131
Mean June–October	1,758	15.6	[3] 74	2,948	20.3	[3] 162	4,706	11.4	[3] 144

[1] Tons per day=(discharge in second-feet) × (p. p. m.) × .0026968.
[2] Analyses made only during latter part of month, May 20–31. Discharges given are means for the entire month.
[3] Averages weighted according to discharge.

TABLE No. 72.—*Comparison of alkalinities observed at station No. 11 with values calculated from observations on the Monongahela and the Allegheny*

[Monthly means, May–October, 1914]

Month	Alkalinity as Ca Co3 at station No. 11			
	Tons per day [1]		Parts per million	
	(A) Observed	(B) Calculated [2]	(C) Observed	(D) Calculated [3]
May	797	1,010	7	8.9
June	228	174	9	6.8
July	102	107	7	7.3
August	70	7	7	0.7
September	191	131	21	14.4
October	131	23	29	5
Mean June–October	144	----------	11.4	6.9

[1] Tons per day=(discharge in second-feet) × (p. p. m.) × .0026968.
[2] Tons per day of alkalinity as Ca Co3 in the Allegheny minus tons per day of acid (in terms of Ca Co3) in the Monongahela as given in Table No. 71.
[3] From data in column (B). Parts per million=(tons per day) ÷ (discharge in second-feet × .0026968).

For the months of May, June, and July the computations thus made are in substantial agreement with actual analyses at station No. 11, but during August, September, and October the alkalinity of the Ohio was very much in excess of the estimates. In view of the recognized inadequacy of the analytical data, and the doubtful precision of discharge estimates for the Monongahela and Allegheny at low stages, the discrepancies are not surprising.

Relative importance of mine drainage and pickling wastes.—It is a matter of some importance, with reference to the anticipated increase of acid pollution in the future, and the practicability of measures for controlling it, to arrive at some estimate of the proportionate amounts of acid contained, respectively, in pickling liquors and in the drainage from coal mines; but from the data at hand nothing more than a rough and quite doubtful estimate can be made.

As regards pickling liquors, discharged as waste from plants engaged in the steel industry, a very careful survey was made during 1914 and 1915 of all the major plants discharging such wastes, and data collected as to the amounts of acid used annually by each. The total for plants located on the watershed above station No. 11 (including the Pittsburgh metropolitan district) amounted to approximately 230 tons per day of acid in terms of equivalent $CaCO_3$. For the pickling process, as commonly applied, a 10 per cent solution of the acid is prepared and used until its content of free acid has been reduced to about 2.7 per cent, when it is discharged as waste. Thus, allowing nothing for recovery processes, which are in use at some plants, about 27 per cent of the acid used would eventually be discharged into the river; that is, about 62 tons per diem.[18] As may be seen from Table 71, this is less than the average amount of free acid actually demonstrable in the Monongahela River alone during the summer of 1914, and less than half the amount present in June. The free acid, however, is only a fraction of the total to be accounted for, since it represents the excess over and above the amount required to neutralize the normal alkalinity of the water.

The normal alkalinity of the Ohio River at Pittsburgh is unknown, but it may be estimated as being in the neighborhood of 50 parts per million. This is inferred from observations on other parts of the watershed, especially on the Beaver River. This stream receives little if any acid mine drainage, but in 1914 received acid pickling liquors estimated at a total of 70 tons per diem in terms of $CaCO_3$. As the mean discharge during this period was 1,760 second-feet, the estimated reduction in alkalinity would be: $70 \div (1760 \times .0026968) = 15$ parts per million. This (15 parts per million) added to the mean alkalinity actually observed in the Beaver (35 parts per million) gives 50 parts per million as the estimated original alkalinity of this stream.

[18] The discharge from individual plants is intermittent, and the amount of acid used varies considerably from year to year and from month to month.

Assuming that in the absence of any acid wastes the normal alkalinity of the Ohio at station No. 11 would be the same as that of the Beaver, that is about 50 parts per million, the difference between this figure and the observed alkalinity may be taken as representing the reduction due to acid wastes. For the period June 1 to October 15, 1914, the mean alkalinity observed at station No. 11 was 11 parts per million (Table 71), indicating a reduction of $50-11=39$ parts per million, which, with the observed mean discharge of 4,706 second-feet, represents approximately 495 tons per day of acid, in terms of equivalent $CaCO_3$. In comparison with this amount the 62 tons per day previously accounted for in waste pickling liquors represents about 12.5 per cent of the total, leaving the remainder of 87.5 per cent to be attributed to mine drainage.

It is obvious that these figures are merely estimates, and of questionable validity, since they are based upon assumptions as to the normal alkalinity of the river and as to the reactivity of acid salts, which, in this computation, are disregarded. If it be assumed, however, that the ferrous salts contained in pickling liquors are entirely removed from solution by reaction with alkaline salts in the river, then the total effect credited to these wastes would be a reduction of alkalinity amounting to 230 tons per diem or about 46 per cent of the total (495 tons) to be accounted for. The true value presumably lies somewhere between these two extremes, that is somewhere between 12.5 and 46 per cent, but probably nearer to the former than to the latter figure. In any case, it seems safe to conclude that the acid originating in mine drainage is very considerably in excess of that discharged in spent pickling liquors. This is in agreement with the opinion held commonly by engineers and others who, in the absence of quantitative data, have based their opinions upon a general knowledge of the sources of pollution. It is also confirmed by the observation that the total amount of free acid carried by the Monongahela is greatest at high river stages, when the drainage from mines is increased in amount.

Estimate of future conditions.—As to the future, it is to be anticipated that in the natural course of events the acid wastes discharged into the river will tend to increase rather than to decrease. This tendency would seem to be inevitable in the case of drainage from coal mines, since any new mines developed will add to the total, while the abandonment of those now being worked will not eliminate them as sources of acid pollution, for it is established that the acid drainage from abandoned mines continues indefinitely. It may likewise be anticipated that the steel industries using pickling processes will continue to expand; but this does not necessarily imply an increase in resultant wastes, since it is possible that recovery processes may come into more general use, perhaps even reducing the present pollution from this class of sources.

With reference to the figures already cited for the months from June to October, 1914, the total acid discharged into the river above station No. 11 during that period has been estimated at about 495 tons (in terms of $CaCO_3$) per diem, and the average residual alkalinity at station No. 11 at 144 tons per diem. To the extent that these figures may be accepted, they indicate that 144 tons per diem of acid added to the present total of 495 tons; that is, an increase of a little less than 30 per cent, would render the Ohio acid at station No. 11 at low-river stages. This estimate is not to be taken too literally; but with all due allowances for uncertainties of computation, it is evident that the margin of residual alkalinity in the Ohio above Wheeling is already quite narrow. In fact, as already stated, samples taken at station No. 11 during the course of this study were occasionally found to be acid, and since then the occasional occurrence of acidity has been reported from points as far downstream as Marietta, Ohio, 170 miles below Pittsburgh.

SUMMARY

The problem of acid-waste pollution is so complex and is influenced by so many varying factors that the data at hand do not permit any precise analysis of existing or forecast of future conditions. However, the following conclusions appear to be justified:

1. The Monongahela at its mouth is consistently acid during the months of low discharge.
2. The alkalinity of the Allegheny, though reduced far below its normal value was usually sufficient, in 1914, to prevent the incursion of free acid into the Ohio, but with a quite narrow margin in reserve against the effect of further increase in acid wastes.
3. Mine drainage is responsible for a major share in the acid pollution of the streams in question, and pollution from this source may be reasonably expected to increase.
4. Acid pickling liquors play a minor, but not precisely determined part in the existing acid pollution. The contribution from this source may either increase or decrease, depending upon the extent to which recovery processes are used.

All acidity values recorded in this report refer to volumetric acidity as ordinarily determined by titration. Acid conditions are, therefore, defined in terms of the methyl orange end-point (about pH 4). This definition is probably too severe since at pH 5, or thereabouts, a water could still be called unduly acid. In view of the fact that simplified procedures are now available for the estimation of the true acidity of river water, the inclusion of this test in future studies appears highly desirable.

ORGANIC CONSTITUENTS

The pollution which is of most serious importance from the sanitary viewpoint, as having the most bearing upon danger to health and offensiveness to sight and smell, is pollution with unstable organic matter from various sources, the most important being the wastes from human habitations, the excreta of lower animals, organic wastes from certain industrial processes, and organic matter chiefly of vegetable origin from the soil. Since the organic wastes from these different sources vary widely with respect to danger and offensiveness, it would be desirable to differentiate between them; but unfortunately this can be done only to a limited extent and more or less indirectly by present-day procedures of chemical analysis.

The measures, or rather indices of organic matter commonly employed in chemical analyses of water and sewage are:

(1) Determinations of nitrogen, differentiated according to the form or combination in which present.

(2) Determinations of the amount of oxidizable material in terms of the amount of oxygen required for its oxidation when treated with permanganate of potash under standardized but altogether artificial conditions.

(3) The determination, by biochemical tests, of the so-called "biochemical oxygen demand"; that is, of the amount of oxygen required for oxidation of the organic matter under conditions which purport to approximate those obtaining in nature.

As these are all standard procedures, and as the determinations of nitrogen and "permanganate oxygen consumed" have been in use for many years, it is unnecessary to enter into a detailed discussion of their significance and limitations, which are assumed to be generally understood.

In planning the laboratory studies of the Ohio River, considerable doubt was felt that these conventional determinations of nitrogen and of oxygen consumed would yield results of sufficient significance to justify the labor and expense of making them. They were, however, included chiefly for the following reasons:

(1) It has been customary in the past to give a prominent place to these determinations in the study of polluted streams, and it was thought that observations in these terms might serve to connect this with previous studies better than observations in terms of bacteria or biological oxygen demand.

(2) Studies by many observers over a long period of years have accumulated data from which a reasonable estimate may be made of the amount of nitrogen or oxygen consumed in the sewage of a given sewered population, and less satisfactory estimates of the

amounts contained in wastes from certain industries. It was thought, therefore, that a knowledge of these constituents in the river might afford a basis for estimating the relative polluting influence of these wastes as compared with the run-off from unsewered areas.

(3) It was considered possible, though hardly probable, that the processes of natural purification in the river might be traced through the observed changes in these constituents, especially the transformations of nitrogen, in long stretches of river below large cities.

I. NITROGEN

The results of the nitrogen determinations made in this study are given in full in Table No. 50, as monthly means, showing, for each month, the nitrogen as free ammonia, albuminoid ammonia, nitrates, and nitrites, as observed at all stations. From October 1, 1914, determinations of nitrogen as free and albuminoid ammonia were discontinued and the determination of "organic nitrogen," including free ammonia, by the Kjeldahl process was substituted, as being more in accordance with present practice and probably more significant. From such studies as have been made of the data in these tables, it appears profitable to consider the results, not in the detailed form there given, but converted into terms of "organic and ammonia nitrogen," "nitrogen oxides," and "total nitrogen."

General significance.—"Organic and ammonia nitrogen" is the nitrogen determined by the Kjeldahl process without separation of the nitrogen as free ammonia. This is considered to be an index of the nitrogenous organic matter present in unstable and generally complex combination, plus that present as ammonia in an intermediate stage of conversion to simpler and more stable forms. As the Kjeldahl determination was not used in our analyses until October 1, 1914, the figures given for previous months are assumed equivalents, calculated by adding the nitrogen as free ammonia to three times the nitrogen as albuminoid anmmonia.[19]

The use of this, or any other constant for conversion of albuminoid ammonia determinations into terms of organic nitrogen is, of course, subject to valid criticism, as the relation is more or less variable. The results thus converted appear, however, to be quite as consistant as they are in terms of the original determinations; and seem to be more, rather than less significant.

The nitrogen as oxides or "mineral nitrogen," is taken as the sum of the nitrogen determined as nitrites and nitrates. In the analyses here given, with few exceptions, the nitrogen as nitrite is insignificant

[19] According to the Standard Methods for the Examination of Water and Sewage (4th ed., 1920, p. 20), the organic nitrogen, exclusive of free ammonia, in surface waters containing but little pollution, is about twice the nitrogen as albuminoid ammonia. In the waters of the Ohio River, however, the organic nitrogen appears to be more nearly three times the nitrogen as albuminoid ammonia, so far as any judgment can be formed from the limited data available.

in amount compared with that as nitrate, so that nitrogen as oxides is practically equivalent to nitrogen in combination as nitrate. As found in surface waters it represents either the nitrogen originally added as nitrate or that received as organic matter in more complex and unstable form, which has undergone full oxidation in the water-course.

"Total nitrogen" is calculated as the organic, and ammonia nitrogen, plus nitrogen as nitrate and nitrite. It is considered as an index of the total amount of nitrogenous matter present, regardless of the form, whether unstable and unoxidized, fully oxidized, or in an intermediate stage. According to present conceptions, the total nitrogen determinable by analysis is not affected by changes in its state of combination. Therefore, while the organic nitrogen may be decreased and the nitrate nitrogen increased by biochemical reactions taking place in a stream, these reactions would make no change in the amount of total nitrogen present. In passage downstream the concentration of total nitrogen, that is, the amount per unit of volume, may be increased or decreased by additional inflow of water containing a higher or lower concentration of nitrogen; but in either case the absolute amount (concentration × volume), necessarily increases. The total amount of nitrogen found in a stream at any given point is, therefore, a measure of all the nitrogen received from all sources upstream, less such amounts as may have been lost by sedimentation taken up by living organisms which are not included in the samples analyzed or liberated in gaseous form or combinations. In the presence of an abundant oxygen supply, the amount lost as a gas is probably not large, and in a river like the Ohio, any loss by sedimentation is presumably temporary, being compensated by ultimate solution or scouring up of the deposited material. The nitrogen taken up by living organisms in the stream or on its banks is also ultimately returned in large part if not entirely. Therefore, the total amount of nitrogen passing a given cross section of the stream over any considerable period of time should approximately equal the total amount received by the stream above this point during the same period. In this particular, total nitrogen differs from all other chemical and biological indices of organic matter in river water.

Summary of analyses.—The mean results of determinations of nitrogen in terms of total nitrogen and proportion of nitrogen oxides at all sampling stations on the Ohio River and its major tributaries are summarized by months for the period January 1st to October 15th, in Table No. 73. The means for longer periods, namely, (1) January–March, (2) April–May, (3) June–October, and (4) January–October, 1914, are shown in Table No. 74, which also gives the separate values of organic and ammonia nitrogen, and nitrogen oxides.

Considering first the averages for the whole period,[20] January to October, 1914, which may be taken as fairly representative of a full seasonal cycle, certain of the results are compared in Table No. 75 with analyses of the waters of various rivers in the United States, and with typical sewage and effluents from sewage treatment plants. This table, in the first place, illustrates what is already well understood, that rivers which are relatively free from gross sewage pollution vary widely in their nitrogen content, probably because of differences in the character of their drainage areas. For example, in this table, Macoupin Creek, Ill., and the Licking River stand in striking contrast to the Kennebec and Potomac Rivers. The comparisons also show that with respect to nitrogen content, the Ohio is intermediate between the extremes observed in the rivers of this country, standing in about the same class as the Lower Mississippi.[21]

TABLE No. 73.—*Summary of nitrogen determinations at sampling stations on Ohio River and tributaries*

[Monthly means, January–October, 1914]

Sampling stations	January		February		March		April		May	
	Total nitrogen (parts per million)	Oxides (per cent of total)	Total nitrogen (parts per million)	Oxides (per cent of total)	Total nitrogen (parts per million)	Oxides (per cent of total)	Total nitrogen (parts per million)	Oxides (per cent of total)	Total nitrogen (parts per million)	Oxides (per cent of total)
Ohio River:										
5–11	0.98	42.0	1.13	47.5	0.92	24.3	1.05	45.9	0.84	22.7
65									.69	22.2
88									.70	26.3
104									.89	45.2
348	.94	51.1	1.28	41.0	1.17	39.6	.99	37.9	.94	25.5
358	1.05	51.6	1.45	38.9	1.34	36.9	1.09	40.8	.93	29.1
461	.97	45.6	1.38	50.1	1.21	54.1	1.00	32.5	.88	23.1
482	.99	44.8	1.49	45.1	1.32	45.9	1.43	30.4	1.09	26.9
598	1.16	57.3	2.99	43.3	1.73	51.8	1.27	40.8	1.04	28.2
619	1.21	50.1	2.16	34.1	1.74	53.6	1.49	52.6	1.08	27.9
904									1.41	28.6
933									1.30	28.7
Allegheny 1 and 7	.83	44.8	1.07	56.2	.84	42.1	1.13	42.7	.75	10.9
Monongahela 1 and 12	.96	34.6	.79	61.5	.77	35.7	1.05	40.3	1.04	26.1
Beaver									1.28	36.6
Scioto	2.27	64.2	3.34	60.2	2.81	55.5	2.00	68.4	1.72	38.8
Little Miami	1.77	73.5	2.97	52.6	2.12	60.7	1.16	54.7	1.34	38.1
Licking	1.75	76.7	2.64	71.3	2.11	68.6	.97	41.5	1.18	32.4
Miami							2.23	72.5	1.38	51.4
Cumberland									1.61	28.3
Tennessee									.70	12.1

[20] The means for these periods are calculated as the averages of the monthly means, thus giving equal weight to each month regardless of the number of samples collected.

[21] The Ohio is also comparable to the Hudson at Albany, N. Y., the Merrimac at Lawrence, Mass., and the James at Richmond, in total nitrogen content according to data for these rivers, given by Flinn, Weston & Bogert, loc. cit.

TABLE No. 73.—*Summary of nitrogen determination at sampling stations on Ohio River and tributaries*—Continued

Sampling stations	June		July		August		September		October	
	Total nitrogen (parts per million)	Oxides (per cent of total)	Total nitrogen (parts per million)	Oxides (per cent of total)	Total nitrogen (parts per million)	Oxides (per cent of total)	Total nitrogen (parts per million)	Oxides (per cent of total)	Total nitrogen (parts per million)	Oxides (per cent of total)
Ohio River:										
5–11	1.33	10.9	0.96	25.2	1.54	16.2	1.96	10.5	1.64	10.8
65	1.05	29.2	.66	46.6	1.33	22.6	1.21	21.2	1.22	34.2
88	1.08	29.9	1.04	33.5	1.34	26.6	1.05	19.5	1.06	27.2
104	1.14	20.0	1.00	29.9	1.39	22.9	1.34	19.9	------	------
348	.63	36.9	1.03	35.0	.91	29.0	1.22	27.0	.99	31.5
358	.69	26.4	.83	46.0	.81	34.1	.96	31.2	.76	38.4
461	.60	30.0	.67	41.2	.88	32.4	1.04	35.1	.76	46.2
482	.86	26.3	.84	39.4	.92	27.1	1.18	39.9	1.05	30.7
598	.94	30.0	.99	23.2	1.11	27.9	1.10	30.4	.92	44.4
619	1.05	26.8	.92	25.0	1.23	24.8	1.14	29.7	1.16	41.1
904	.84	24.6	.72	8.6	1.54	7.7	1.30	27.6	.85	24.3
933	.74	21.8	1.00	21.1	.93	20.7	1.85	13.9	.76	20.2
Allegheny 1 and 7	.72	14.2	.73	22.2	.96	23.4	.82	16.1	1.20	17.2
Monongahela 1 and 12	1.15	21.0	.92	19.6	1.31	5.4	1.49	10.2	1.25	12.1
Beaver	1.52	19.8	1.27	31.8	1.94	19.7	1.65	21.7	1.10	33.0
Scioto	1.03	19.9	1.26	15.7	1.02	14.3	1.42	25.6	.84	21.7
Little Miami	------	------	------	------	------	------	------	------	------	------
Licking	1.29	47.4	.86	.7	2.39	34.7	1.58	57.3	.89	45.8
Miami	------	------	1.48	29.7	1.32	34.3	1.79	28.4	1.30	35.3
Cumberland	1.02	48.4	1.62	25.5	1.12	53.2	1.56	35.1	1.23	26.3
Tennessee	.78	15.8	.72	18.3	.87	36.1	.73	27.8	.78	28.4

TABLE No. 74.—*Mean results of nitrogen determinations at sampling stations on the Ohio River and tributaries for four periods in 1914*

Sampling stations	January to March				April and May			
	Parts per million nitrogen as—			Oxides, per cent of total nitrogen	Parts per million nitrogen as—			Oxides, per cent of total nitrogen
	Organic and ammonia (a)	Oxides (b)	Total (c)		Organic and ammonia (a)	Oxides (b)	Total (c)	
Ohio:								
5 and 11	0.62	0.39	1.01	38.6	0.65	0.34	0.95	35.8
65	------	------	------	------	[1] .54	[1] .15	[1] .69	21.8
88	------	------	------	------	[1] .52	[1] .18	[1] .70	25.7
104	------	------	------	------	[1] .49	[1] .40	[1] .89	45.0
348	.64	.49	1.13	43.4	.66	.31	.97	32.0
358	.75	.53	1.28	41.5	.65	.36	1.01	35.6
461	.59	.60	1.19	50.5	.67	.26	.93	28.0
482	.69	.57	1.27	44.9	.89	.36	1.26	28.6
598	1.00	.99	1.98	50.0	.75	.40	1.15	34.8
619	.95	.76	1.71	44.5	.74	.54	1.29	41.9
904	------	------	------	------	[1] 1.01	[1] .40	[1] 1.41	28.4
933	------	------	------	------	[1] .93	[1] .37	[1] 1.30	28.4
Allegheny, 1 and 7	.47	.44	.91	48.4	.66	.28	.94	29.8
Monongahela, 1 and 12	.47	.36	.84	42.9	.70	.35	1.04	33.7
Beaver	------	------	------	------	[1] .81	[1] .47	[1] 1.28	36.8
Scioto	1.13	1.68	2.81	60.0	.84	1.02	1.86	55.0
Little Miami	.91	1.38	2.29	60.3	.68	.57	1.25	45.6
Licking	.61	1.56	2.16	72.2	.68	.39	1.07	36.5
Miami	------	------	------	------	.64	1.16	1.80	64.5
Cumberland	------	------	------	------	[1] 1.15	[1] .46	[1] 1.61	28.6
Tennessee	------	------	------	------	[1] .62	[1] .08	[1] .70	11.4

TABLE No. 74.—*Mean results of nitrogen determinations at sampling stations on the Ohio River and tributaries for four periods in 1914*—Continued

Sampling stations	June to October				January to October			
	Parts per million nitrogen as—			Oxides, per cent of total nitrogen	Parts per million nitrogen as—			Oxides, per cent of total nitrogen
	Organic and ammonia (a)	Oxides (b)	Total (c)		Organic and ammonia (a)	Oxides (b)	Total (c)	
Ohio:								
5 and 11	1.28	0.20	1.48	13.5	0.95	0.28	1.23	22.8
65	.77	.32	1.09	29.4				
88	.81	.30	1.11	27.0				
104	.94	.28	1.22	23.0				
348	.66	.30	.96	31.3	.65	.36	1.01	35.6
358	.52	.29	.81	35.8	.62	.37	.99	37.4
461	.50	.29	.79	36.7	.56	.38	.94	40.5
482	.65	.32	.97	33.0	.71	.41	1.12	36.7[1]
598	.70	.31	1.01	30.7	.80	.53	1.33	39.9
619	.77	.33	1.10	30.0	.82	.50	1.32	37.9
904	.86	.19	1.05	18.1				
933	.86	.20	1.06	18.9				
Allegheny, 1 and 7	.72	.16	.88	18.2	.63	.27	.90	30.0
Monongahela, 1 and 12	1.07	.16	1.23	13.0	.81	.26	1.07	24.2
Beaver	1.13	.36	1.50	24.0				
Scioto	.89	.22	1.11	19.8	.96	.81	1.77	45.8
Little Miami								
Licking	.85	.55	1.40	39.2	.74	.82	1.57	52.3
Miami	[2] 1.01	[2] .46	[2] 1.47	31.3				
Cumberland	.84	.47	1.31	35.8				
Tennessee	.58	.20	.78	25.6				

[1] May only. [2] July–October

TABLE No. 75.—*Nitrogen content of water from the Ohio River at different sections, compared with analyses of samples from various other rivers, and of sewage*

Character of source with reference to sewage pollution	Source of samples	Parts per million of nitrogen as—			Oxides (per cent of total)
		Total nitrogen	Organic and ammonia	Oxides	
(A) Subject to only slight and remote sewage pollution.	Kennebec River at Augusta, Me.[1]	0.43	0.39	0.04	9.3
	Potomac River at Washington, D. C.[1]	.45	.34	.11	24.4
	Licking River at Latonia, Ky.[2]	1.57	.75	.82	51.6
	Macoupin Creek, Ill. at mouth tributary of Illinois River, draining rural area.[3]	2.07	1.46	.61	29.4
(B) Receiving sewage from large urban populations more than 100 miles distant.	Mississippi River at New Orleans, La.[1]	.86	.74	.12	14.0
	Illinois River at Kampsville, Ill. about 300 miles below Chicago and 125 miles below Peoria, Ill.[3]	2.92	1.50	1.42	48.7
	Ohio River at Sta. 461, above Cincinnati.[2]	1.01	.63	.38	37.6
	Ohio River at Sta. 598, above Louisville.[2]	1.33	.80	.53	39.9
(C) Receiving sewage from large urban population immediately above.	Ohio River at Stas. 5 and 11, below Pittsburgh.[2]	1.23	.95	.28	22.8
	Ohio River at Sta. 482, below Cincinnati.[2]	1.12	.71	.41	36.7
	Ohio River at Sta. 619, below Louisville.[2]	1.32	.82	.50	37.9
	Illinois River at Joliet, Ill. (immediately below outlet of Chicago Drainage Canal.)[3]	3.48	3.26	.22	6.3
(D) Urban sewage	Raw sewage, Washington, D. C.[4]	14.69	14.00	.69	4.9
	Average for four large cities, combined sewage.[5]	19.11	18.60	.55	2.9
(E) Sewage effluents	Average analysis for effluents from sand filters.[6]	20.77	11.36	7.89	38

[1] Flinn, Weston & Bogert. Waterworks Handbook, 2d ed. New York, 1918. McGraw-Hill. p. 668. Computed from data there given.
[2] Original data, this report.
[3] Original data, U. S. P. H. S., Illinois River investigation, 1921–22.
[4] Cumming, H. S. Investigation of the Pollution of the Potomac Watershed. Hyg. Lab. Bull. No. 104, Washington, D. C., 1916. Gov't. Ptg. Office. p. 125.
[5] From data given by Metcalf and Eddy. American Sewerage Practice. McGraw-Hill Book Co., New York, 1916. Vol. III, p. 181.
[6] Ibid, p. 663. Organic and ammonia nitrogen estimated from figures as free and albuminoid ammonia.

Range of variation.—Referring to Tables Nos. 73 and 74, perhaps the most significant single fact shown in relation to this study, is that the range of variation between different sampling stations on the Ohio River is very narrow, and that the variations are not consistently related to the known extent of fresh sewage pollution. Whether the comparison be made upon the basis of organic or total nitrogen, the sections of the Ohio river exposed to gross pollution from the sewage of large cities discharged a few miles upstream (stations Nos. 11, 482, and 619), show little or no consistently higher pollution than do sections remote from direct sewage pollution (stations Nos. 348, 461, 598, 904, and 933); and frequently less than tributaries such as the Little Miami, Licking, Cumberland, and Tennessee, which drain areas with relatively little urban population. Considering all the sampling stations on the Ohio during the 10 months from January to October, 1914, the extreme ranges of variation observed are as follows:

Nitrogen as—	Maximum			Minimum			Ratio, maximum to minimum
	Parts per million	Station	Month	Parts per million	Station	Month	
Total	3.06	598	February	0.604	461	June	5.05
Organic and ammonia	1.76	11	September	.39	461	July	4.52
Oxides	1.40	598	February	.12	904	August	11.80

This is a remarkably narrow range of variation as compared with that in content of bacteria or even in turbidity or discharge, showing that nitrogen determinations are not a sensitive index of physical and biochemical changes in the Ohio.

Evidences of oxidation.—In general, as shown by Tables Nos. 73 and 74, the concentration of nitrogen, total, organic and oxides, tends to increase in passage downstream from Pittsburgh, notwithstanding that the ratio of urban population to run-off is constantly decreasing (see p. 66). This increase is evidently accounted for by the high nitrogen content of tributaries below the Beaver. However, the figures are not entirely without consistency in relation to known sewage pollution, for, except during the periods of high discharge there is a fairly consistent decrease in organic nitrogen from Pittsburgh to station 461, above Cincinnati; and an increase, though slight, in passage past Cincinnati, and again in passing Louisville.

During the high-water periods, January to March, and April to May, there is no consistently significant increase in the ratio of nitrogen oxides to total nitrogen in passage downstream, such as would be expected if oxidation were taking place at a fairly rapid rate. There

is, however, a definite and more or less consistently progressive increase in this ratio from Pittsburgh (station 11) to Portsmouth (station 348) during the low-water period June–October, when the time of passage downstream is much prolonged. Below Portsmouth, the ratio remains fairly constant to station 619, but it is unexpectedly low at the lower end of the river, at stations 904 and 933.

Quantitative significance of total nitrogen determinations.—The applicability of nitrogen determinations to measurement of the effect of the direct sewage pollution from individual cities, even very large cities, upon the Ohio River may be illustrated by a study of the observed effect of the wastes from Cincinnati upon the nitrogen content of the stream. Between station 461, above Cincinnati, and station 482, below the city, the Ohio River receives the inflow of two tributaries, the Little Miami and the Licking Rivers, and the sewage from the Cincinnati metropolitan district, having, in 1915, about 594,700 inhabitants, of whom about 494,300 were served by the sanitary sewerage systems.

As samples from the Little Miami and the Licking River were taken above the points where they receive any considerable sewage pollution from the Cincinnati metropolitan district and as the discharge curves of these streams are known, their effect upon the main stream may be calculated. Thus, the results of nitrogen determinations at station 461 on the Ohio, and at sampling stations on the Little Miami and the Licking, weighted according to discharge and averaged, give the concentration of nitrogen which the Ohio would be expected to show at station 482, exclusive of the influence of Cincinnati sewage. Therefore, the difference between the observed nitrogen at station 482 and this weighted average, if determined with sufficient precision, would represent and measure the effect of the sewage from the Cincinnati metropolitan district.

As stated in a previous section of this report, the total nitrogen in the domestic sanitary sewage and industrial wastes discharged into the river from the Cincinnati metropolitan district may be estimated as follows:

	Kilos per diem
Allowing 15 grams per capita per diem for domestic sanitary sewage from 494,300 sewered population	7, 415
Estimated nitrogen content of industrial wastes from Cincinnati metropolitan district, based upon a census of industries (Table 48, p. 82)	4, 857
Total estimated nitrogen constantly discharged into the river through sewers from this district	12, 272

Since 2,446,589 grams per diem is equivalent to 1 part per million in a discharge of 1,000 second-feet, the increase in parts per million resulting from 12,272 kilos per diem discharged into a given volume expressed in second-feet may be readily calculated.

Table No. 76 shows, for each of the 17 months from January, 1914, to June, 1915, for which data are available, excluding December, 1914, on account of incomplete data:

1. The mean discharge of the Ohio at station 482, which equals the discharge at station 461, plus the discharge of the Little Miami and Licking Rivers.

2. Parts per million of nitrogen observed at station 461 and 482, respectively, being the means of the separate analyses made during each month. The mean figures given for station 461, are averages of the observations at that station, the Little Miami and Licking Rivers, weighted according to their respective discharges.

3. The differences, in parts per million of total nitrogen, between stations 482 and 461 (weighted average): (*a*) As actually observed, and (*b*) as expected from the above estimate of the amount of nitrogen in the sewage of the Cincinnati district and the prevailing mean discharge of the river.

4. The same differences, actual and calculated, expressed as percentages of the total nitrogen observed at station 461.

The results are arranged in ascending order according to mean discharge.

TABLE No. 76.—*Comparison of stations 461, above Cincinnati, and 482, below the city, with respect to total nitrogen*

[Monthly means, January, 1914, to May, 1915]

Month	Mean discharge, second-feet [1]	Total nitrogen, parts per million at—		Total nitrogen difference, station 482–station 461			
				Parts per million		Per cent of amount at station 461	
		Station 461 and tributaries [2]	Station 482	Observed	Calculated from estimate of Cincinnati sewage [3]	Observed	Calculated from estimate of Cincinnati sewage [3]
November, 1914	11,776	0.911	1.260	+0.349	0.426	+38.3	46.7
August, 1914	15,190	.950	.920	−.030	.330	−3.2	34.8
October, 1914	16,922	.812	1.426	+.614	.297	+75.6	36.5
September, 1914	17,490	1.048	1.184	+.136	.287	+13.0	27.4
July, 1914	18,950	.669	.845	+.176	.265	+26.3	39.6
June, 1914	21,010	.638	.859	+.221	.239	+34.6	37.5
April, 1915	41,640	.737	.825	+.088	.120	+11.9	16.3
May, 1915	56,070	1.858	1.824	−.034	.089	−1.8	4.8
June, 1915	74,270	1.783	1.724	−.059	.067	−3.3	3.8
March, 1915	84,243	1.008	.912	−.096	.060	−9.5	6.0
January, 1914	99,680	1.008	.987	−.021	.051	−2.1	5.1
May, 1914	126,030	.892	1.086	+.194	.040	+21.8	4.5
March, 1914	160,000	1.280	1.320	+.040	.032	+3.1	2.5
February, 1914	172,980	1.454	1.493	+.039	.029	+2.7	2.2
January, 1915	183,770	1.186	1.043	−.143	.028	−12.6	2.4
February, 1915	245,100	1.391	1.540	+.149	.021	+10.7	1.5
April, 1914	247,930	.998	1.426	+.428	.020	+42.9	2.8

[1] Sum of the discharges at station 461, plus the Little Miami and Licking Rivers. This equals discharge at station 482.

[2] Monthly means at 461, Little Miami and Licking Rivers, weighted by respective discharges and averaged.

[3] Calculated from an estimate of 12,272 kilos per diem as amount of nitrogen contained in the sewage of the Cincinnati metropolitan district.

According to the analysis of experimental errors which has previously been presented (pp. 129–142) the "probable error" of the difference between monthly means of determinations at two sampling stations would appear to be in the neighborhood of ± 10 per cent, though doubtless varying for different stations and different determinations. In this instance, considering that the total nitrogen is computed from determinations of nitrogen in three different forms, and that the observations at station 461 are weighted averages for three streams, the experimental error is quite likely greater than this, and a "probable error" of 10 per cent may be considered as a minimum rather than a liberal estimate. With a probable error of this magnitude, errors two or three times as great may be expected to occur occasionally; and an actual difference is not measurable with any degree of certainty unless it is several times as great as the "probable error."

During the seven months in which the discharge of the river was less than 50,000 second-feet, the calculated increase in nitrogen between stations 461 and 482, ranged from 0.12 to 0.43 parts per million, corresponding to an increase of 16 to 47 per cent over the amount observed at station 461. Differences of this order are doubtless too small, in relation to the "probable error" to be individually measurable with any degree of precision, but in a series of observations they should be sufficiently consistent in their direction to be distinguishable from random errors of observation. The observed differences in these seven months are actually consistent to the extent that in six of the seven months, station 482 shows a significant increase; an irrational result, that is, an indicated decrease at station 482 occurring only once; and in this instance the observed decrease is less than half the assumed probable error. As regards this particular observation, reference to the records of the individual analyses made during the month (August, 1914) shows that the higher average at station 461 results from a single sample collected on August 31, on which date no sample was collected from station 482. At that time, following a heavy rainfall and sudden rise in the river stage, the Ohio was unusually turbid, and the nitrogen content unusually high. Omitting this sample and basing the comparison upon the remaining six samples collected from station 461 on the same dates as from station 482, the monthly mean at station 461 (weighted average including the Little Miami and Licking) would be 0.816 instead of 0.950 part per million; and upon this basis the result at station 482 (0.920 part per million) would show an increase of 0.104 part per million, or 12.1 per cent over station 461.

During the remaining ten months, when the discharge of the river was between 50,000 and 250,000 second-feet, the calculated increase between stations 461 and 482 amounted to only 0.02 to 0.09 part per million, which is only 1.5 to 6 per cent of the amount observed at station 461. As would be expected under these circumstances,

an indicated decrease is shown at station 482 as frequently as an increase, since the expected differences to be measured are less than the probable error of the observations.

The obvious conclusion from these facts is that nitrogen determinations, as made in this study, are not sufficiently precise to measure the effect of the sewage from a city of 500,000 population upon the Ohio River at moderate and high stages. The inapplicability of these determinations need not be ascribed, however, to excessive errors in the technique of sampling and analysis. It is due to the fact that the range of actual variation to be measured is extremely narrow; and it is improbable that any practicable elaboration of technique in sample collections and analysis could so reduce the observational error as to insure reliable measurement of such small variations. It is only in periods of low discharge in the river, when the effect of the comparatively constant sewage flow is proportionately increased, that the effect becomes distinguishable, and even then it is measurable only in a rough sense and by repeated observations.

The observed additions of nitrogen to the river during the seven months of low discharge, though admittedly not precisely measurable, may be compared with the estimates previously and independently made of the amount of nitrogen contained in the sewage of the Cincinnati metropolitan district. Converting the differences between station 482 and station 461, as shown in Table No. 76, into terms of kilograms per diem, the indicated additions of nitrogen are as summarized in Table No. 77, following:

TABLE No. 77.—*Observed amounts of total nitrogen added to the Ohio River in passage past Cincinnati, in months when discharge of river was less than 50,000 second-feet*

Month	Mean discharge (second-feet)	Observed additions of nitrogen	
		Parts per million	Kilograms per diem
November, 1914	11, 776	0. 349	10, 100
August, 1914	15, 190	[1]. 104	[1] 3, 860
October, 1914	16, 922	. 614	25, 400
September, 1914	17, 490	. 136	5, 820
July, 1914	18, 950	. 176	8, 160
June, 1914	21, 010	. 221	11, 400
April, 1914	41, 640	. 088	8, 960
Averages	20, 425	. 241	10, 520

[1] Omitting one day's observation at station 461.

The values for individual months are widely dispersed, as might be expected, but the average for the whole period of seven months, 10,520 kilos per diem, is in reasonably close agreement with the estimate of 12,370 kilos. The observed increase, 10,520 kilos, corresponds to a contribution of 21.3 grams per capita of sewered population, including industrial wastes. This is well within the range of amounts estimated for other cities from volumetric measurements and analyses of their collected sewage. Exclusive of the amount, 4,857 kilos per diem, estimated as originating in organic industrial wastes, the in-

dicated per capita contribution of nitrogen during this period was 11.46 grams. This is less than the estimate of 15 grams per capita which is used elsewhere in this report, but is an entirely reasonable figure upon the basis of studies made elsewhere. Moreover, it is to be expected that there would be some temporary loss of nitrogen during periods of low water, due to sedimentation of sewage solids; and the figure of 15 grams per capita used in our calculations was adopted as a liberal rather than an exact estimate. The agreement between the estimated and the observed additions is, on the whole, sufficiently close to confirm the reasonableness of both the estimate and the observations.

Surface drainage and urban sewage as sources of nitrogen.—Applying an estimate of 15 grams of nitrogen per capita per day for the sewered population of the watershed, and adding the amount estimated to be contained in organic industrial wastes as given in Section III, a rough estimate may be made of the total amount of nitrogen contained in the domestic and industrial urban sewage discharged into the Ohio directly or indirectly from various subdivisions of its watershed. Comparison of this apparently liberal estimate with the total amount of nitrogen actually carried in the river, as determined by analyses and discharge measurements, may then serve to give some idea of the relative importance of urban sewage and natural surface drainage as sources of the nitrogenous matter found in the river. Table No. 78 presents the necessary data for such comparisons at two points on the Ohio River and on two tributary watersheds for the 10 months, January to October, 1914, also for the period of relatively high run-off, January to May, and the period of low run-off, June to October.

TABLE No. 78.—*Observed amounts of nitrogen (kilograms per diem) carried by the Ohio River at three sampling stations, and by two tributaries, compared with amounts estimated as originating in sewage of urban population*

Watershed	10 months, January–October, 1914, moderate discharge				5 months, January–May, 1914, high discharge			5 months, June–October 1914, low discharge		
	Mean discharge (thousands second-feet)	Total nitrogen			Mean discharge (thousands second-feet)	Total nitrogen		Mean discharge (thousands second-feet)	Total nitrogen	
		Observed in river (kilos per diem)	Accounted for in urban sewage			Observed in river (kilos per diem)	Accounted for in urban sewage		Observed in river (kilos per diem)	Accounted for in urban sewage
			Kilos per diem	Per cent of total in river			Per cent of total in river			Per cent of total in river
Ohio River:										
Above station 348	73.70	179,000	59,600	33	134.60	386,000	15	12.84	25,400	235
Above station 461	83.82	192,000	64,900	34	151.20	402,000	16	16.40	31,700	204
Scioto River	6.65	28,800	5,280	18	12.50	74,200	7	.80	2,180	242
Licking River	3.89	14,900	143	.96	6.61	28,000	.5	1.14	3,910	3.7

Considering the whole period, January to October, as fairly representative of average conditions in the river, it is seen that the nitrogen estimated as contained in urban sewage accounts for only one-third

or less of the total amounts carried by the Ohio at the three points of observation cited; and for an even smaller proportion of the amounts carried by the Scioto and Licking Rivers. During the period of higher average discharge, January to May, the proportion accounted for as sewage is even smaller, about 16 per cent of the total at Ohio River stations, and from 0.5 to 7 per cent on the tributaries. The plain inference is that under average and high water conditions the major part of the nitrogenous matter which finds its way into the river system is derived from surface drainage, not from urban sewage.

During the period of low discharge, the nitrogen estimated as contained in urban sewage is sufficient to account for more than twice the total found in the Ohio and the Scioto, but only a small percentage in the Licking. This need not be taken, however, as indicating that all the nitrogen present in the Ohio at low stages is actually of sewage origin, although the relative effect of sewage pollution is undoubtedly increased. In the first place, the discharge of urban sewage is not entirely constant, tending to be somewhat less during periods of dry weather, when solids accumulate in the sewers and in the small streams into which they frequently discharge. Also, the amount found in the river at low water stages does not necessarily represent the total received above the point of observation, for under low water conditions the tendency is generally toward sedimentation rather than scour; and abstraction of nitrogen by living aquatic organisms is probably at its maximum. If the observed decreases in turbidity may be taken as an index of the extent of removal of solids by sedimentation, this factor alone might readily account for the (temporary) loss of well over 50 per cent of the suspended nitrogenous matter in the several hundred miles of waterway above the points of observation. Again, the estimate applied to urban sewage is, as above noted, an intentionally liberal estimate, considerably in excess of that ordinarily applied.

If, as is indicated by the foregoing data, the chief source of the nitrogen in the Ohio River at moderate and high stages is natural drainage, variations in the amount of nitrogen carried should be closely associated with variations in the amount of surface drainage, that is, total run-off. That such is actually the case is illustrated by Table No. 79, which shows, for stations 348, 461 and 482 on the Ohio, and for the Scioto and Licking Rivers: (*a*) The mean discharge, and (*b*) the amount of nitrogen carried in kilos per diem for each month, January to October, 1914, the data for each station being arranged in ascending order of monthly mean discharge. From this table it is readily apparent that the amount of nitrogen carried varies directly with discharge, the nitrogen increasing generally in somewhat higher proportion than the discharge, indicating a tendency towards higher concentration of nitrogen at the higher river stages.

TABLE No. 79.—*Relation between discharge and amount of nitrogen carried in Ohio River at various points and in two tributaries*

[Monthly means, January-October, 1914]

Station 348		Station 461		Station 482		Scioto River		Licking River	
Discharge (second-feet)	Total nitrogen (kilos per diem)	Discharge (second-feet)	Total nitrogen (kilos per diem)	Discharge (second-feet)	Total nitrogen (kilos per diem)	Discharge (second-feet)	Total nitrogen (kilos per diem)	Discharge (second-feet)	Total nitrogen (kilos per diem)
4, 400	8, 190	12, 700	23, 600	15, 200	34, 180	490	1, 002	110	220
11, 800	23, 400	13, 900	29, 800	16, 900	43, 500	730	2, 251	230	888
13, 700	32, 200	17, 100	43, 550	17, 500	50, 670	810	2, 814	740	4, 330
16, 400	33, 300	18, 700	30, 560	19, 000	39, 170	960	2, 400	1, 030	3, 250
17, 900	30, 200	19, 800	29, 260	21, 000	44, 160	1, 000	2, 520	3, 370	14, 430
90, 800	233, 300	94, 900	225, 200	99, 700	240, 700	5, 050	28, 040	3, 600	7, 790
101, 000	229, 800	120, 200	257, 600	126, 000	335, 000	6, 950	29, 240	4, 000	11, 550
133, 000	436, 400	147, 700	437, 300	160, 000	516, 800	14, 200	116, 000	5, 670	13, 430
138, 000	490, 300	156, 100	527, 800	173, 000	632, 000	17, 200	84, 160	6, 830	35, 260
210, 000	560, 500	237, 100	577, 200	247, 800	864, 300	19, 100	131, 300	13, 200	85, 240

A further indication of the preponderating influence of surface drainage rather than urban sewage upon the nitrogen content of the river is its relation to turbidity, which may be taken as an index of the extent of soil erosion, and to rainfall, which has already been shown to be an important controlling factor in erosion. Table No. 80 shows the monthly means of turbidity, total nitrogen and "oxygen consumed" in parts per million, at stations 461 and 482 during the two full years, 1914 and 1915, the observations on "oxygen consumed" being added for comparison with the nitrogen. The monthly means are arranged in decreasing order of turbidity.

TABLE No. 80.—*Relations between turbidity, total nitrogen, and oxygen consumed determinations at stations 461 and 482, on the Ohio River*

Parts per million					
Station 461			Station 482		
Turbidity [1]	Total nitrogen	Oxygen consumed	Turbidity [1]	Total nitrogen	Oxygen consumed
490	4. 03	7. 10	559	1. 824	11. 80
394	1. 69	9. 50	427	3. 141	9. 10
283	. 95	11. 65	379	1. 724	9. 10
213	1. 38	6. 07	369	1. 229	14. 27
213	1. 04	6. 68	300	2. 191	10. 10
204	1. 26	6. 30	270	1. 493	6. 29
167	2. 31	8. 60	251	1. 040	8. 10
159	1. 34	7. 00	189	1. 501	8. 30
153	. 99	4. 60	179	1. 540	6. 30
153	1. 04	3. 45	174	1. 086	3. 50
146	. 93	7. 50	173	. 920	2. 77
145	. 87	3. 36	167	1. 135	6. 50
140	1. 08	4. 70	156	1. 052	5. 70
138	. 87	3. 87	125	1. 426	6. 60
126	1. 22	5. 40	120	1. 320	4. 70
113	. 97	4. 47	104	. 987	4. 20
113	1. 21	4. 20	102	. 859	4. 04
109	. 72	2. 50	100	1. 426	2. 85
83	1. 25	5. 70	92	. 912	6. 10
79	. 96	3. 84	91	1. 340	5. 60
28	. 73	2. 46	84	1. 184	3. 35
22	. 66	2. 20	26	. 825	3. 10
14	. 89	4. 04	23	. 845	2. 40
12	. 60	1. 78	16	1. 260	4. 67
QUARTILE AVERAGES					
299. 5	1. 725	7. 883	384. 0	1. 933	10. 110
153. 8	1. 247	5. 752	188. 8	1. 204	5. 912
123. 2	1. 012	4. 190	117. 8	1. 178	4. 682
39. 7	. 848	3. 337	55. 3	1. 061	4. 203

[1] Turbidities as given in Table No. 50.

Simple inspection of this table, especially of the averages, shows, both at 461 and 482, a positive and apparently high correlation of total nitrogen and oxygen consumed with turbidity. The coefficients of correlation derived from this table are as follow:

	Coefficients of correlation	
	Station 461	Station 482
Turbidity and total nitrogen	+0.761±0.058	+0.664±0.077
Turbidity and oxygen consumed	+ .704± .069	+ .826± .044

The coefficients of correlation are all sufficiently high and sufficiently in excess of their probable errors to be definitely significant, indicating that at these points on the river, soil erosion, as measured by turbidity, is an important factor presumably the most important factor in determining the proportion of organic matter present in the water as measured either by total nitrogen or by oxygen consumed determinations. That this should be the case at station 461, which is remote from any considerable direct sewage pollution, is as expected. It is, however, somewhat surprising that there should be substantially the same degree of correlation at station 482 which is exposed to the full effect of pollution from the sewage of Cincinnati.

2. Determinations of Oxygen Consumed by Permanganate Test

The results of determinations of oxygen consumed by the standard permanganate test, as made at all sampling stations during the year 1914, are summarized in Table No. 81 by months, and Table No. 82 gives a more condensed summary of the averages for the entire 10 months and for the two periods, January to May and June to October, representing, respectively, conditions of generally high and quite low river stages. In Table No. 83 the observations at four stations on the Ohio are compared with recorded analyses of water from several other rivers in the United States.

This determination is customarily included in the routine of sanitary chemical analyses as affording an index of organic matter supplementary to that given by nitrogen determinations, and has been included in the schedule of this study in deference to custom rather than in the expectation that the determinations would be of very considerable significance.

TABLE No. 81.—*Summary of results of permanganate oxygen consumed determinations upon samples from the Ohio River and tributaries, January–October, 1914*

[Monthly means]

Sampling stations	Parts per million oxygen consumed: Monthly means									
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct. 1–15
Allegheny 1–7 [1]	3.22	4.90	3.70	3.90	3.65	2.82	3.00	3.37	4.48	3.36
Monongahela 1–12 [2]	3.89	3.04	3.40	3.10	1.85	2.10	2.90	3.50	3.51	2.17
Ohio:										
5–11 [3]	3.80	5.32	4.10	2.90	3.45	2.49	1.80	3.30	3.96	2.70
65					3.23	3.11	2.80	2.21	3.23	3.10
88					3.73	3.41	2.50	3.09	3.84	5.42
104					2.50	2.23	2.90	3.19	3.32	
348	3.91	6.39	4.40	3.50	4.51	1.58	2.90	5.02	3.91	3.72
358	4.19	7.02	4.70	4.10	5.60	1.60	2.50	4.14	3.98	3.12
461	4.47	6.07	4.20	4.60	3.87	1.78	2.20	3.36	3.45	2.82
482	4.20	6.29	4.70	6.60	3.50	4.04	2.40	2.77	3.35	2.35
598	4.28	10.29	5.10	5.00	4.38	2.29	3.00	3.53	4.11	2.99
619	4.82	8.58	6.30	4.40	3.98	3.44	3.30	4.07	4.36	4.00
904					4.32	4.34	5.00	3.23	4.43	3.65
933					5.20	4.62	3.00	4.03	3.76	3.95
Beaver River				7.30	3.84	2.63	2.70	2.80	3.33	3.26
Scioto River	4.24	7.90	6.40	3.20	5.20	3.18	4.00	4.40	4.41	3.95
Little Miami River	4.42	7.70	4.80	4.90	4.82					
Licking River	2.52	5.40	3.50	5.70	3.80	14.95	4.30	5.06	4.08	3.20
Miami River					4.00		4.50	3.25	3.90	3.70
Cumberland River					4.00	4.10	3.60	2.80	4.13	4.92
Tennessee River					1.60	4.20	3.20	2.84	3.53	4.58

[1] Samples from station A–1 January–April, inclusive; thereafter from A–7.
[2] Samples from station M–1 January–April, inclusive; thereafter from M–12.
[3] Samples from station O–5 in January, February, and August; all others from O–11.

TABLE No. 82.—*Mean results of oxygen consumed determinations upon samples from the Ohio River and tributaries for designated periods, January–October, 1914*

Sampling stations	Parts per million oxygen consumed, means for designated periods		
	January–October	January–May	June–October
Allegheny 1–7 [1]	3.64	3.87	3.41
Monongahela 1–12 [2]	2.95	3.06	2.84
Ohio River:			
5–11 [3]	3.38	3.91	2.85
65		[4] 3.23	2.89
88		[4] 3.73	3.65
104		[4] 2.50	2.91
348	3.98	4.54	3.43
358	4.09	5.12	3.07
461	3.68	4.64	2.72
482	4.02	5.06	2.98
598	4.50	5.81	3.18
619	4.72	5.62	3.83
904		[4] 4.32	4.13
933		5.20	3.87
Beaver River		[5] 5.57	2.94
Scioto	4.69	5.39	3.99
Little Miami		5.33	
Licking	5.25	4.18	6.32
Miami		[4] 4.00	3.84
Cumberland		[4] 4.00	3.91
Tennessee		[4] 1.60	3.67

[1] Station A–1, January–April, inclusive; A–7, May–October.
[2] Station M–1, January–April, inclusive; M–12, May–October.
[3] Station O–5, January, February, April; O–11 for all other months.
[4] Result for month of May only.
[5] Average of April and May only.

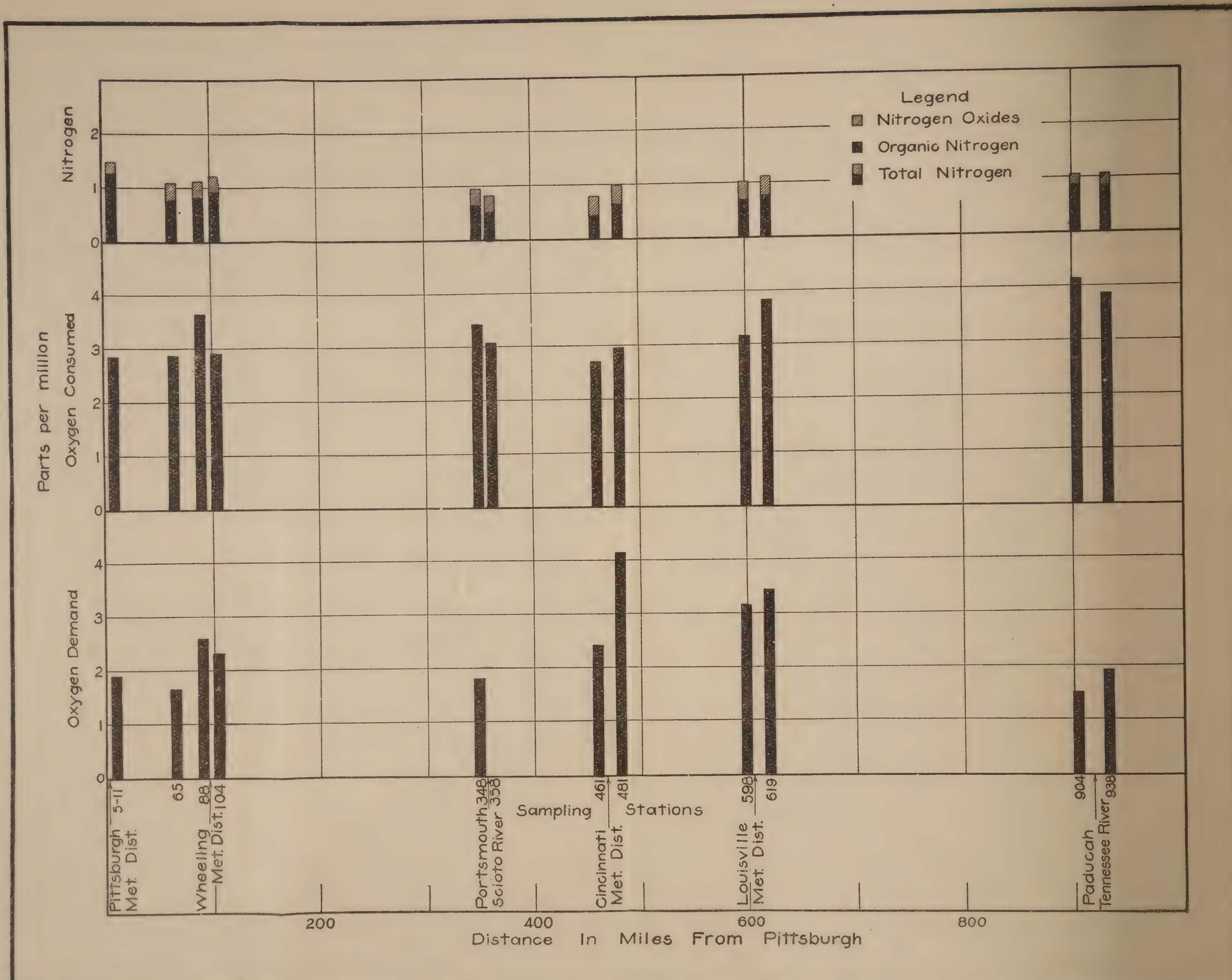

FIG. 25.—Mean concentration (parts per million) of biological oxygen demand, oxygen consumed (permanganate test), and total nitrogen at principal sampling stations on the Ohio River during period of low water, June to October, 1914

95404°—24† (Face p. 183.) No. 1

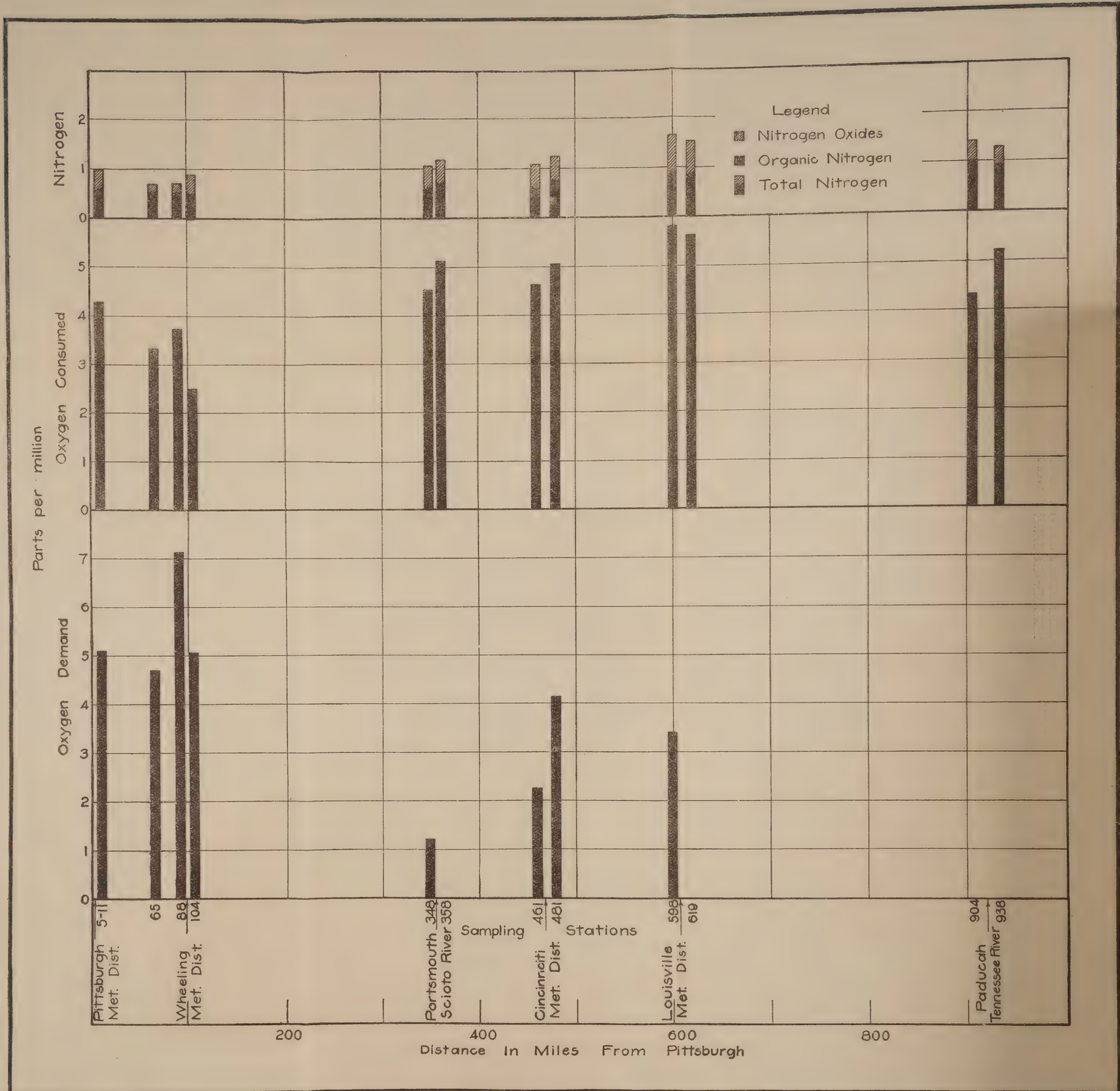

FIG. 26.—Mean concentration (parts per million) of biological oxygen demand, oxygen consumed (permanganate test), and total nitrogen at principal stations on the Ohio River during period of high water, January to May, 1914

95404°—24†. (Face p. 183.) No. 2

TABLE No. 83.—*Average values of oxygen consumed in various rivers of the United States as compared with the Ohio*

River	Sampling station	Mean oxygen consumed
Allegheny	Pittsburgh, Pa	[1] 3.20
Delaware	Philadelphia, Pa	[1] 3.70
Hudson	Albany, N. Y	[1] 5.51
James	Richmond, Va	[1] 1.65
Mississippi	Minneapolis, Minn	[1] 7.60
Do	New Orleans, La	[1] 6.90
Missouri	Omaha, Nebr	[1] 7.1
Potomac	Washington, D. C	[1] 2.6
Ohio	Station 461, above Cincinnati	[2] 3.7
	Station 482, below Cincinnati	[2] 4.0
	Station 598, above Louisville	[2] 4.5
	Station 619, below Louisville	[2] 4.7

[1] From Flinn, Weston and Bogert, Waterworks Handbook, McGraw-Hill, New York, 1st ed., p. 668.
[2] Originial data; averages for 10 months, January–October, 1914.

As may be seen from Tables Nos. 81 and 82, and from Figures 25 and 26, the results are in a general way parallel to those of total nitrogen determinations. As between different stations and different months, the range of variation in oxygen consumed is somewhat narrower than in total nitrogen; and the values show the same tendency to increase in passage downstream in high river stages and to decrease in low stages as was noted in the case of total nitrogen. There is also a similar correlation with run-off; and, as shown in Table No. 80, with turbidity. The effect of the large volumes of sewage discharged into the river from the Cincinnati and Louisville districts is not indicated consistently by an observed increase in the concentration of oxygen consumed, and even in low-water periods is not measurable with any degree of accuracy.

On the whole, oxygen consumed values in the Ohio River are a somewhat less sensitive index of sewage pollution than total nitrogen, and while the results of the two determinations are generally consistent, it appears that the determination of oxygen consumed yields little if any information of value that is not given by nitrogen determinations.

3. Biochemical Oxygen Demand

The determinations of dissolved oxygen and of biochemical oxygen demand, as summarized in Table No. 51, probably yield more significant information concerning the organic pollution of the river than do the determinations of nitrogen and of oxygen consumed in the standard permanganate tests which have been discussed above. The dissolved oxygen determinations were, however, made with a view chiefly to their application in a study of the laws governing the rates of oxidation and aeration in the river, and as the data of Table 51 are discussed from this viewpoint in a separate study [22] which follows this report, it is superfluous to discuss them here.

[22] A study of the pollution and natural purification of the Ohio River, III, Factors concerned in the phenomena of oxidation and reaeration, by H. W. Streeter and E. B. Phelps. Public Health Bulletin, No. 146.

Section VI

BACTERIOLOGICAL STUDIES

By W. H. Frost and H. W. Streeter

PART I

EXTENT AND SOURCES OF BACTERIAL POLLUTION

The general purposes of the bacteriological studies, as previously stated (Section IV, p. 88), were:

1. To determine the extent and range of pollution during a representative cycle of seasonal and hydrographic conditions in those zones of the river which are most important from the standpoint of hygiene, namely:

(*a*) Zones from which water supplies must be taken for large cities.

(*b*) Zones immediately below large cities which discharge raw sewage into the river, these being the zones where, presumably, the limits of toleration will first be overpassed.

2. To determine and so far as possible to measure the effect of certain individual factors in contributing to the observed status of pollution, namely:

(*a*) Sewage from large urban populations discharged directly into the river.

(*b*) Inflow of important tributaries.

(*c*) Action of natural agencies, physical and biological, tending chiefly toward bacterial and chemical purification of the stream.

The considerations governing the location of sampling stations to serve these purposes, the schedules of sample collections followed, and the details of technique employed have already been explained in a preceding section.

As a total of more than 25,000 samples were examined the results can not be presented in detail, and they are therefore given, as are other data, chiefly in the form of monthly averages, in two basic tables, as follows:

Table No. 84, in which the data are arranged by sampling stations, summarizes, in monthly averages, the results of all the bacteriological examinations made at each sampling station, the sampling stations being arranged in consecutive order proceeding downstream from Pittsburgh. In addition to bacteriological results, this table in-

cludes certain collateral data which, though previously presented in part in other sections, are repeated here for convenience of reference, namely:

(1) The distribution and total number of days on which samples were collected from each station in each month.

(2) The mean temperature of the river at each station, from observations made simultaneously with the collection of samples.

(3) The mean river stage, as shown on the reference gage for each station, being the mean of daily gage reading throughout the month.

(4) The mean discharge of the river at each sampling station, in second-feet.

(5) The results of turbidity readings made parallel with the bacteriological examinations.

As observations at a number of stations were discontinued on October 15, 1914, the summaries for the other stations show mean values for the period October 1 to 15, 1914, in addition to means for the full month of October.

In Table No. 85 the data shown in Table No. 84 are rearranged by months, summarizing the results at all stations from which samples were collected during the given month. This arrangement permits convenient comparison of simultaneous observations at various points on the Ohio River, and comparison of conditions on tributary streams with those on the main stream at the junction points. In addition to the summary for the whole month of October, 1914, a separate summary is given for the period October 1 to 15.

The collateral data in this table are the same as in Table 84, with the addition of mean time of flow, in hours, from Pittsburgh to each Ohio River station for the months, January to October, 1914. In the summaries for the whole month of October, 1914, and for succeeding months when observations were limited to the river stretch from Cincinnati to Louisville, the time of flow is given from station 475, immediately below Cincinnati, to each sampling station below, these being the time intervals most used in analyses of the data for periods after October 15, 1914.

These two tables, together with the more detailed hydrographic data presented in Section II, the population distributions given in Section III and the sampling schedules given in Section IV, furnish the basic data used in most of the discussions which follow, and the supplementary tables inserted in the text are either rearrangements of the identical data presented in the basic tables, or derivatives from them, such as ratios. Where such derivatives are used, the basic figures from which they are computed are ordinarily not repeated, since they are accessible in the basic tables.

In computing the monthly means given in the basic tables an occasional observation on a single day has been omitted because of its extreme divergence from preceding and subsequent observations; but this has been done only in accordance with definite rules of procedure ; and in each instance where such an omission has been made it is noted in the table by reference to a footnote. The total number of such omissions is small, and except in the few extreme cases noted all observations have been included in computing averages, with no attempt to smooth the results.

TABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*

[Terms "daily" and "alternate" as applied to sample collections signify daily or on alternate days exclusive of Sundays and legal holidays.
Mean temperatures refer to temperature of the river, being means of observations made at the time of sampling.
Averages for stations 461 to 619 are given separately for the period Oct. 1 to 15 and Oct. 1 to 30, 1914, the former being for comparison with results at other stations, where observations were discontinued Oct. 15. Owing to a general change in hydrographic conditions during the latter half of October, 1914, the means for the whole month differ materially from those for the period Oct. 1 to 15.]

SAMPLING STATION A-7—ALLEGHENY RIVER AT ASPINWALL, UPPER LIMIT OF PITTSBURGH

[River stages at U. S. Weather Bureau gage, Freeport, Pa.]

Months	Dates of sample collections	Total days samples taken	Monthly means						
			Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Turbidity (p. p. m.)	Bacteria per c. c. on—		B. coli per c. c. (est.)
							Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	
1914									
March [1]	Daily, 17th–31st, except 18th, 23d.	11	4.7	12.8	37,000	71	7,690	640	8
April [2]	Daily, except 2d	25	7.3	11.6	48,100	50	2,180	400	12
May [3]	Daily, 18th–29th	11	19.3	[4] 10.2	32,800	11	5,850	6,250	15
June	Daily	26	23.0	3.6	6,530	20	8,200	20,700	44
July	Daily, except 4th, 15th, 16th, 17th.	23	24.5	2.1	3,460	16	4,560	9,460	34
August	Daily, except 11th	25	23.0	1.4	1,660	15	7,420	22,900	78
September	Daily, except 7th, 30th	24	19.0	1.6	2,250	18	10,200	16,000	105
October	Daily, 1st–15th, except 1st, 7th, 8th.	10	17.0	.9	840	16	1,720	8,350	44

SAMPLING STATION A-1,—ALLEGHENY RIVER AT SIXTH STREET, PITTSBURGH

[River stage, U. S. Weather Bureau gage, Freeport, Pa.]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. coli per c. c. (est.)
1914									
January	Daily, except 1st, 13th, 14th, 19th, 20th, 29th, 31st.	20	0.9	6.6	21,800	62	--------	1,110	162
February [5]	2d–6th	5	2.4	11.3	25,600	71	--------	1,560	207
March	Daily, except 2d–4th, 16th–18th, 21st, 23d, 31st.	17	2.3	12.8	37,000	48	--------	1,620	246
April	Daily, except 1st, 2d, 18th	23	9.2	11.5	48,100	55	4,420	1,420	114

[1] Samples taken from surface during March and April.
[2] Samples taken from only one point, in midstream, during April.
[3] Sample collections discontinued, May 1–17, because of lack of facilities for collections.
[4] No record of gage readings, May 20–31.
[5] Sample collections discontinued Feb 7 to Mar. 4, inclusive, because of floating ice in river.

TABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION M-12—MONONGAHELA RIVER ABOVE PITTSBURGH

[River stage refers to 7 a. m. readings at U. S. Weather Bureau gage (Ohio River) Pittsburgh. No satisfactory gage on the Monongahela]

Months	Dates of sample collections	Total days samples taken	Monthly means						
			Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Bacteria per c. c. on—		B. Coli per c. c. (est.)
							Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	
1914									
March [1]	Daily, except 2d, 3d, 9th	23	3.7	7.7	[2] 20,200	55	1,370	120	8.0
April [3]	Daily, except 6th, 7th, 21st, 24th.	22	10.1	11.0	31,100	53	2,230	200	12.0
May [4]	Daily, 18th–31st, except 30th.	11	[5] 23.5	6.9	9,400	12	80	41	3.0
June	Daily	26	24.0	5.8	2,850	12	400	220	1.0
July	Daily, except 4th, 15th–17th.	23	24.9	6.1	1,920	8	55	[6] 100	2.0
August	Daily, except 4th, 5th, 11th.	23	24.8	6.0	2,070	4	30	22	0.7
September	Daily, except 6th, 23d	23	21.0	6.0	1,120	5	20	18	0.4
October	Daily, 1st–15th, except 1st, 7th, 8th.	10	19.7	6.1	830	11	10	11	0.2

SAMPLING STATION M-1—MONONGAHELA RIVER ABOUT 1 MILE ABOVE MOUTH

[River stage: Refers to 7 a. m. readings at U. S. Weather Bureau gage (Ohio River), Pittsburgh. No satisfactory gage on the Monongahela]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
January	Daily, except 1st, 13th, 14th, 19th, 20th, 29th, 31st.	20	1.0	5.8	[7] 17,000	85	--------	360	64
February [8]	Daily, 2d–6th	5	2.4	6.4	16,600	62	--------	560	104
March	Daily, except 2d, 5th, 16th–18th, 31st.	18	3.8	7.7	20,200	58	4,210	780	124
April	Daily, except 1st, 2d, 18th	23	10.7	11.0	31,100	68	2,670	470	26

SAMPLING STATION 3—OHIO RIVER, 3 MILES BELOW "POINT," AT PITTSBURGH

[River stage: Refers to 7 a. m. readings at U. S. Weather Bureau gage, Pittsburgh.]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
January	Daily, except 1st, 13th, 14th, 19th, 20th, 29th, 31st.[9]	20	1.0	5.8	38,800	89	--------	440	86
February	2d–6th only [10]	5	2.4	6.4	42,200	81	--------	1,010	226
March	Daily 5th–26th, except 16th–18th, 25th.	15	1.4	7.7	57,200	53	7,400	950	169
April	No samples	--------	--------	11.0	79,200	--------	--------	--------	--------
May	Daily, 5th–29th	22	15.8	[11] 6.9	42,200	62	5,330	2,440	196
June	Daily, except 30th	25	24.0	[11] 5.8	9,380	38	9,470	15,200	220
July	Daily, except 4th, 14th	25	25.1	[11] 6.1	5,380	5	5,300	10,600	127
August	Daily	26	25.0	[11] 6.0	3,730	7	4,290	[12] 14,500	110
September	Daily, except 5th, 7th	24	21.0	[11] 6.0	3,370	14	35,400	41,100	726
October	Daily, 1st–15th	13	19.0	[11] 6.1	1,670	14	6,900	[13] 53,900	255

[1] Samples taken at surface during March and April. After May 17 taken at mid-depth, at accurately located points.
[2] Discharge calculated as difference between discharge of the Ohio River at Pittsburgh and that of the Allegheny.
[3] Samples taken from only one point (center) during April.
[4] No samples collected May 1 to 17, inclusive.
[5] Temperature records for May 25–29 only.
[6] Anomalous agar counts of 27th omitted in taking average. Including these results, average for month would be 135.
[7] Discharge calculated as equal to difference between discharge of the Ohio River at Pittsburgh and that of the Allegheny.
[8] Sample collection omitted Feb. 7–Mar. 5 on account of floating ice.
[9] Samples from surface until May 4, 1914, thereafter from mid-depth at accurately located points.
[10] Sample collections discontinued Feb. 7–Mar. 4 on account of ice in river; discontinued Mar. 27–May 4, on rearrangement of schedule.
[11] Gage in backwater during whole or part of the month.
[12] Excluding excessively high agar count of Aug. 28, average would be 9,020.
[13] Omission of excessively high agar counts Oct. 3 and 5 would give average of 27,800.

TABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION 5—OHIO RIVER, 5 MILES BELOW "POINT" AT PITTSBURGH

[River stage: Refers to 7 a. m. readings at U. S. Weather Bureau gage, Pittsburgh]

Months	Dates of sample collections	Total days samples taken	Monthly means						
			Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C., 48 hours	Bacteria per c. c. on— Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
January	Daily, except 1st, 13th, 14th, 19th, 20th, 29th, 31st.	20	1.0	5.8	38,800	86	--------	310	80
February	2d-6th, only	5	2.4	6.4	42,200	78	--------	820	177
March	Daily, 5th-30th, except 16th, 18th, 26th.	18	2.2	7.7	57,200	61	5,810	760	179
April	Daily, 3d-30th	24	9.9	11.0	79,200	60	3,280	900	88

SAMPLING STATION 11—OHIO RIVER, 1 MILE BELOW DAM NO. 3

[River stage: Refers to 7 a. m. readings at U. S. Weather Bureau gage, Pittsburgh]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
March [1, 2]	Daily, 10th-30th, except 11th, 12th, 16th-19th.	12	3.0	7.7	57,200	69	2,800	280	10
April [1]	3d, 4th, 6th, 11th	4	7.1	11.0	79,200	66	2,640	600	20
May	Daily, 5th-29th	22	16.0	[3] 6.9	42,200	62	2,850	1,280	76
June	Daily	26	25.0	5.8	9,380	52	3,160	10,200	37
July [4]	Daily, except 4th, 23d, 24th	24	24.7	6.1	5,380	4	640	3,420	15
August [4]	Daily, except 12th	25	24.6	6.0	3,730	4	495	2,000	34
September	Daily, except 7th, 30th	24	20.5	6.0	3,370	10	1,850	3,060	110
October	Daily, 1st-15th, except 1st, 7th, 8th.	10	18.3	6.1	1,670	8	790	1,300	148

SAMPLING STATION 19—OHIO RIVER, ½ MILE BELOW DAM NO. 4[5]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
April	Daily, 7th-30th, except 11th, 24th.	19	10.3	11.0	79,200	67	2,750	500	24
May	Alternate [6]	13	16.0	[7] 6.9	42,200	57	2,100	1,100	58
June	Alternate	13	24.0	[7] 5.8	9,380	50	1,520	3,380	23
July	Alternate, 1st-20th, except 6th. [7]	8	24.2	[7] 6.1	5,380	7	1,000	3,100	35
August	Alternate, 14th-31st	8	24.4	[7] 6.0	3,730	7	740	1,400	75
September	Alternate, 2d-28th, except 7th.	11	20.5	[7] 6.0	3,370	13	1,200	1,100	134
October	Alternate, except 7th (1st-15th).	5	18.8	[7] 6.1	1,670	18	1,220	1,450	70

[1] Samples from surface until May 4; thereafter from mid-depth at accurately located points.
[2] Sample collections irregular during March on account of unfavorable weather conditions.
[3] Gage in backwater (pool stage) during whole or part of month.
[4] Sample collections discontinued at this station July 22-31, and Aug. 1, 3, 10, 11, and 12, because of repairs to lock at Dam No. 2. Samples were collected during this period from a point about 2 miles upstream above Dam No. 2. Monthly average results include the samples from the latter point.
[5] Samples from mid-depth at carefully located points.
[6] After May 1 sample collections made every other day alternating with collections at Station No. 23.
[7] Sample collections discontinued July 21 to Aug. 13, because of repairs to lock at Dam No. 2, interfering with launch service.

TABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION 23—OHIO RIVER, ½ MILE ABOVE DAM NO. 5[1]

[River stages: U. S. Weather Bureau gage, Pittsburgh]

Months	Dates of sample collections	Total days samples taken	Monthly mean: Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
April	Alternate, 8th–30th, except 10th, 16th, 25th.	7	11.7	11.0	79,200	58	2,400	620	29
May	Alternate, 5th–28th, plus 27th.	12	16.0	[2] 6.9	42,200	64	4,100	1,780	64
June	Alternate	13	23.4	[2] 5.8	9,380	18	3,900	6,830	40
July [3]	Alternate, 2d–21st, except 4th, 7th, 14th.	6	24.5	[2] 6.1	5,380	7	1,040	5,340	118
August [3]	Alternate, 13th–29th	8	24.0	[2] 6.0	3,730	7	[4] 1,020	2,100	28
September	Alternate	13	20.3	[2] 6.0	3,370	15	900	[5] 1,920	106
October	Alternate, 3d–15th, except 8th.	5	17.9	[2] 6.1	1,670	21	1,140	1,250	123

SAMPLING STATION BEAVER—BEAVER RIVER AT MOUTH (CONFLUENCE WITH OHIO BETWEEN STATIONS NOS. 23 AND 29)[6]

[River stage: U. S. P. H. S. gage, Wampum, Pa., July–October. No gage prior to July 1]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
April	Daily, 7th–30th, except 8th, 11th, 24th.	18	9.7	-------	[7] 11,800	93	12,000	3,000	180
May	Daily, except 2d, 30th, 31st.	24	17.0	-------	7,480	85	6,260	[8] 3,460	235
June	Daily	26	23.4	-------	850	26	3,960	2,830	190
July	Daily, 1st–21st, except 4th, 6th, 11th. [9]	15	23.8	.680	460	11	5,070	7,850	502
August	Daily, 13th–31st [9]	16	23.0	.485	360	17	6,440	11,200	550
September	Daily, except 7th, 11th, 30th.	23	19.0	.530	390	17	9,190	9,860	775
October	Daily, 1st–15th, except 1st, 7th, 8th.	10	16.0	.253	240	15	7,720	6,520	640

SAMPLING STATION 29—OHIO RIVER, ½ MILE BELOW DAM NO. 6, ABOUT 4 MILES BELOW MOUTH OF BEAVER RIVER[10]

[River stages: U. S. Weather Bureau gage, Pittsburgh]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
April	Alternate, 7th–29th, except 13th.	10	9.6	11.0	91,000	84	5,000	934	18
May	Alternate, 1st–22d	10	14.4	[11] 6.9	49,700	86	5,140	3,340	142
August	Alternate, except 26th	12	25.0	[11] 6.0	4,090	3	922	1,560	24
September	Alternate, 2d–18th, except 7th.	7	20.7	[11] 6.0	3,760	5	1,420	2,030	197

[1] Samples from mid-depth at accurately located points; alternating with collections at No. 19.
[2] Gage in backwater (pool stage) during whole or part of month.
[3] Sample collections discontinued July 22–Aug. 12, because of repairs to lock at Dam No. 2, interrupting launch service.
[4] Excluding excessively high gelatin count at one point on Aug. 13, average would be 520.
[5] Omitting excessively high agar counts on Sept. 1, average for month would be 1,410.
[6] Samples from mid-depth in midstream—one point only.
[7] Discharge at mouth.
[8] Excessive and anomalous agar count of May 1 omitted in taking average. Including this result, average for month would be 6,220.
[9] Sample collections discontinued July 22–Aug. 12, because of repairs to lock at Dam No. 2, interfering with launch service.
[10] Samples from mid-depth at accurately located points. Sample collections discontinued during June and July because of low water interrupting launch service.
[11] Gage in backwater (pool stage).

TABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION 65—OHIO RIVER ABOVE STEUBENVILLE, OHIO

[River stage: U. S. Weather Bureau gage, Wheeling]

Months	Dates of sample collections	Total days samples taken	Monthly mean: Temperature, ° C.	Monthly mean: River stage (feet)	Monthly mean: Discharge, (second-feet)	Monthly mean: Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C., 48 hours	Bacteria per c. c. on— Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
May	Alternate, 7th–29th, except 11th.	10	16.6	11.4	55,700	82	--------	519	39
June	Alternate	13	22.7	[1] 6.1	10,300	21	--------	1,580	14
July	Alternate, except 8th	13	24.6	[1] 7.8	6,630	6	890	780	13
August	Alternate, except 7th, 14th, 26th.	10	24.2	[1] 8.2	4,650	4	370	835	19
September	Alternate, except 7th	12	19.8	[1] 8.0	4,500	33	614	384	42
October	Alternate, 1st–15th	6	17.7	[1] 7.8	2,470	5	425	212	7

SAMPLING STATION 77—OHIO RIVER BETWEEN STEUBENVILLE, OHIO, AND WHEELING, W. VA.

[River stages refer to 7 a. m. readings at U. S. Weather Bureau gage, Wheeling]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
May	Alternate, 7th–29th	10	16.8	11.4	55,700	80	--------	565	36
June	Alternate	13	23.7	[2] 6.1	10,300	50	--------	2,280	42
July	Alternate, except 8th	13	25.0	[2] 7.8	6,630	7	1,230	1,260	28
August	Alternate, except 14th, 26th.	11	24.6	[2] 8.2	4,650	13	887	1,640	48
September	Alternate, except 7th	12	20.3	[2] 8.0	4,500	24	1,100	634	82
October	Alternate, 1st–15th	6	18.2	[2] 7.8	2,470	5	614	470	14

SAMPLING STATION 88—OHIO RIVER JUST ABOVE WHEELING

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
May	Daily, 7th–31st, except 11th, 12th, 30th.	18	16.8	11.4	55,700	96	--------	447	28
June	Daily	26	23.7	[2] 6.1	10,300	30	--------	1,540	29
July	Daily, except 8th	25	25.0	[2] 7.8	6,630	11	607	680	72
August	Daily, except 15th, 25th, 26th.	23	24.4	[2] 8.2	4,650	13	670	[3] 720	48
September	Daily, except 7th, 19th	24	20.4	[2] 8.0	4,500	25	530	388	43
October	Daily, 1st–15th	13	18.6	[2] 7.8	2,470	8	352	213	17

SAMPLING STATION 97—OHIO RIVER BELOW WHEELING AND BELLAIRE

[River stage refer to 7 a. m. readings at U. S. Weather Bureau gage, Wheeling]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
May	Alternate, 8th–28th	10	16.3	11.4	55,700	91	--------	627	84
June	Alternate	13	22.6	[2] 6.1	10,300	33	--------	2,680	118
July	-----do	12	24.8	[2] 7.8	6,630	8	[4] 4,240	[5] 3,800	161
August	-----do	13	24.2	[2] 8.2	4,650	12	3,200	[6] 4,330	151
September	Alternate, except 19th	12	20.4	[2] 8.0	4,500	22	1,630	1,570	92
October	Alternate, 1st–15th	7	18.2	[2] 7.8	2,470	8	[7] 3,420	2,460	113

[1] Gage in backwater (pool stage).
[2] Gage in backwater (pool stage, Dam No. 13), June 14–Oct. 15.
[3] Excessive and anomalous agar count of August 13 omitted in taking average. Including this result, average for the month would be 1,330.
[4] Excluding gelatin count of 69,400 at South Point July 1, average would be 2,430.
[5] Excluding agar count of 53,400 at South Point, July 1, average would be 2,590.
[6] Excluding agar count of 31,900 at South Point Aug. 13, average result would be 3,690.
[7] Excluding gelatin count of 24,000 at South Point Oct. 15, average result would be 2,490.

TABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION 104—OHIO RIVER 14 MILES BELOW WHEELING

Months	Dates of sample collections	Total days samples taken	Monthly means: Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
May	Alternate, 8th–28th	9	16.4	11.4	55,700	73	--------	414	72
June	Alternate	13	23.3	[1] 6.1	10,300	49	--------	2,530	92
July	Alternate, except 9th	11	24.8	[1] 7.8	6,630	7	1,640	2,000	35
August	Alternate, except 25th	12	23.9	[1] 8.2	4,650	26	2,500	2,740	212
September	Alternate, except 19th	12	20.3	[1] 8.0	4,500	23	1,520	1,000	49
October	Alternate, 1st–15th	7	18.1	[1] 7.8	2,470	9	3,720	1,500	186

SAMPLING STATION 348 (349)—OHIO RIVER, 6 MILES ABOVE PORTSMOUTH, OHIO[2]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
January	Daily	26	2.3	18.5	90,800	60	--------	816	21
February	Daily, except 7th, 16th–19th, 23d–26th.	15	1.9	25.1	138,000	121	12,500	993	51
March	Daily	26	3.2	24.5	133,000	115	8,200	630	19
April	Daily, except 6th, 9th	24	10.3	34.3	210,000	158	3,400	1,060	33
May	Daily, except 8th, 30th	24	17.0	20.0	101,000	152	1,240	904	25
June	Daily	26	25.5	5.8	17,900	30	334	440	9
July	...do	26	26.7	5.4	16,400	100	872	1,290	29
August	Daily, except 18th	25	25.7	4.0	11,800	90	954	1,720	25
September	Daily, except 7th	25	22.3	4.6	13,700	80	790	816	31
October	Daily, 1st–15th	13	20.2	1.9	4,440	21	522	836	32

SAMPLING STATION 355—OHIO RIVER, IMMEDIATELY BELOW PORTSMOUTH ABOVE MOUTH OF SCIOTO RIVER

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
January	Daily	26	2.3	18.5	90,800	63	--------	870	22
February	Daily, except 5th, 16th, 18th, 23d.	20	1.5	25.1	138,000	132	11,200	1,270	32
March	Daily	26	3.2	24.5	133,000	113	[3] 8,060	745	22
April	Daily, except 6th	25	10.6	34.3	210,000	152	3,220	1,080	32

SAMPLING STATION—SCIOTO RIVER, AT MOUTH[4]

[River stage: U. S. Weather Bureau gage, Chillicothe, Ohio]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
January	Daily	26	2.3	2.2	[5] 5,050	41	--------	2,130	32
February	Daily, except 7th, 16th–18th, 23d.	19	1.6	5.5	[5] 14,200	217	34,600	4,140	71
March	Daily	26	3.2	7.2	[5] 19,100	208	22,400	3,060	37
April	Daily, except 6th	25	12.2	6.1	[5] 17,200	128	6,500	3,500	29
May	Daily, except 4th, 8th, 30th	23	18.6	2.8	[5] 6,950	158	2,500	1,810	71
June	Daily, except 13th	25	24.5	.14	[5] 1,000	91	1,980	2,850	171
July	Daily	26	25.6	−.1	[5] 730	64	1,940	3,000	100
August	Daily, except 18th, 31st	24	24.8	−.1	[5] 960	174	[6] 4,120	[6] 11,400	182
September	Daily, except 7th, 24th	24	21.1	−.07	[5] 810	97	3,600	3,140	89
October	Daily, 1st–15th	13	19.4	−.3	[5] 490	49	3,800	[7] 7,840	182

[1] Gage in backwater (pool stage, Dam No. 13), June 14–Oct. 15.
[2] Location of station changed in April, 1914, and designation changed from 348 to 349. Samples from surface until May, 1914, thereafter from mid-depth.
[3] Excessively high gelatin count (94,000) at South Point, March 9, omitted in calculating average, and more probable figures interpolated. Including this result, average for month would be 9,290. Samples from surface.
[4] Samples from a single point; at mid-depth, in midstream.
[5] Discharge at mouth.
[6] Excessive and unexplained gelatin count (61,300) of Aug. 11, omitted in calculating average. Including this result, monthly average would be 6,920.
[7] Omitting unusually high agar count (51,700) of Oct. 8, average for month would be 4,180.

TABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION (360), 358 [1]

[River stage: U. S. Weather Bureau gage, Portsmouth, Ohio]

Months	Dates of sample collections	Total days samples taken	Monthly means						
			Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C., 48 hours	Bacteria per c. c. on— Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
January	Daily	26	2.3	18.5	95,800	69		1,080	18
February	Daily, 2d–28th, except 5th, 7th, 16th–18th, 23d–26th.	14	1.7	25.1	152,200	174	14,400	1,460	48
March	Daily	26	3.2	24.5	152,100	130	11,100	1,040	19
April	Daily, except 6th, 9th, 10th, 15th–17th, 29th.	19	10.9	34.3	227,200	163	4,000	1,310	33
May	Daily, except 4th, 8th, 30th	23	17.3	20.0	108,000	157	1,670	895	23
June	Daily, except 13th	25	25.3	5.8	18,900	34	424	550	18
July	Daily	26	26.6	5.4	17,100	79	810	1,230	28
August	Daily, except 18th	25	26.6	4.0	12,800	118	[2] 1,600	[2] 2,680	39
September	Daily, except 7th, 8th, 23d, 24th.	22	22.1	4.6	14,500	89	[3] 1,100	[3] 1,330	25
October	Daily, 1st–15th	13	20.0	1.9	4,930	24	720	1,290	22

SAMPLING STATION 461—OHIO RIVER ABOVE CINCINNATI, 1 MILE ABOVE MOUTH OF LITTLE MIAMI

[River stages at Dam 37, lower gage. Gage heights designated (*) indicate that dam was raised during a part or whole of the month forming pool above]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
January	Daily, 5th–31st, except 20th	23	2.2	17.3	94,900	95	19,900	440	17
February	Daily, except 7th, 12th, 16th–20th, 23d, 25th–27th.	13	2.9	25.3	156,100	208	19,500	1,360	50
March	Daily, 4th–31st, except 11th, 13th, 14th, 17th–19th, 23d, 28th.	16	3.4	24.0	147,700	155	18,900	854	20
April	Alternate	14	9.9	32.7	237,100	187	4,620	690	26
May	Alternate, except 8th, 20th	10	17.6	19.9	120,200	138	2,450	390	19
June	Alternate, except 30th	12	26.2	* 5.3	19,800	12	220	190	1
July	Alternate, except 20th	13	27.1	* 4.9	18,700	22	[4] 320	400	7
August	Alternate	13	26.4	* 3.7	13,900	145	1,200	1,260	24
September	Twice weekly	8	22.1	* 4.4	17,100	153	500	1,280	20
October	1st–15th, except 7th	5	20.1	* 1.2	7,210	24	850	1,370	11
Do	Alternate, except 7th, 21st, 28th.	10	18.0	* 3.7	12,700	109	806	3,270	61
November	Alternate	13	7.7	* 2.8	11,400	14	130	120	2
December	Daily, 1st–21st	18	4.7	15.2	81,100	283	4,560	3,630	107
1915									
January	Daily	25	1.2	26.2	171,900	213	13,900	3,420	41
February	Daily, except 1st, 6th, 22d	21	2.7	31.9	223,000	151	10,000	1,350	51
March	Daily, except 12th, 16th	25	3.9	15.4	79,400	80	6,640	560	19
April	Daily	26	12.3	* 9.6	40,000	24	944	[5] 160	5
May	Daily, except 31st	25	19.0	* 11.3	50,900	45	2,930	1,530	72
June	Daily	26	22.2	* 13.9	69,500	281	4,760	2,110	49
July	Daily, except 5th	26	24.9	* 14.2	66,300	369	6,850	3,840	127
August	Daily	26	24.0	* 11.6	50,200	172	4,780	3,150	121
September	Daily, except 6th	25	22.2	* 10.3	48,200	160	3,790	2,300	66
October	Daily	26	16.0	* 13.0	66,200	157	4,400	2,000	65
November	Daily, except 25th	25	10.0	11.0	53,200	89	6,630	2,080	41
December	Daily, except 17th, 24th, 25th.	24	2.9	21.4	125,000	182	18,900	2,420	28

[1] Samples from surface until May 1; thereafter from mid-depth, at accurately located points. Location and designation of station changed from 360 to 358 May 1.

[2] Excessive and unexplained gelatin (103,400) and agar (133,500) counts at Center Point Aug. 28, omitted.

[3] Exclusive of excessive and unexplained gelatin (10,150) and agar (12,600) counts at North Point Sept. 11 monthly averages would be gelatin count 1,100, agar count 1,330.

[4] Excessive gelatin count (6,170) at one point on section July 24, excluded from average. Including this result, average for month would be 464.

[5] Excessive agar count (3,400) at one point on section Apr. 22, excluded from average. Including this result, average for month would be 200.

TABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION 461—OHIO RIVER ABOVE CINCINNATI, 1 MILE ABOVE MOUTH OF LITTLE MIAMI—Continued

Months	Dates of sample collections	Total days samples taken	Monthly means						
			Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1916									
January	Daily, 3d–31st	25	3.2	37.8	273,500	235	29,400	2,940	25
February	Daily	24	3.3	30.3	204,000	207	20,500	1,850	27
March	do	27	3.7	28.4	189,000	329	33,800	2,560	19
April	do	25	9.8	28.5	198,000	107	9,080	704	19
May	do	26	17.2	16.9	92,700	123	3,010	660	12
June	do	26	20.9	18.4	101,000	306	5,850	2,190	61
July	Alternate days	13	26.3	* 10.1	46,100	183	914	949	11
August	do	13	26.1	* 9.8	43,100	506	3,440	3,090	34
September	do	12	22.2	* 4.8	17,400	38	858	661	3
October	do	13	14.9	* 5.6	23,400	51	999	1,160	13
November	do	13	9.0	* 4.7	17,800	19	783	477	5
December	Alternate, except 20th–27th	9	4.3	12.1	56,300	118	13,500	1,100	60

SAMPLING STATION LITTLE MIAMI RIVER

[River stages at U. S. P. H. S. gage at Plainville, Ohio. Gage established in July, 1914. No records of prior gage heights]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
January	Daily, 5th–31st, except 20th.	23	2.8		1,410	171	45,800	640	19
February	Daily, 2d–13th, except 7th, also 21st, 24th, 28th.	12	1.1		3,680	218	53,900	5,060	62
March	Daily, except 1st–3d, 11th, 13th, 14th, 17th, 19th, 23d, 28th.	16	4.8		5,470	225	35,500	3,260	24
April	Alternate, except 20th	13	12.7		5,160	161	17,800	2,970	42
May	Alternate, 4th–25th, except 8th, 20th.	8	18.8		1,830	193	975	926	29
June	Alternate, 12th–29th	8			180	78	3,650	5,500	28
July	Alternate	14			140	272	2,440	3,180	27
August	do	13		6.4	550	333	18,900	11,800	[1] 896
September	Alternate, except 7th	12		5.9	160	44	2,280	2,620	181
October	Alternate, 1st–15th	6		5.8	240	17	3,890	4,740	54
Do	Alternate	13		6.7	622	89	4,180	3,800	112
November	do	13		5.9	148	14	2,590	1,140	43
December	Alternate, except 23d, 28th	10		7.6	1,030	108	19,000	12,400	152
1915									
January	Alternate, 8th–22d	7		8.8	2,610	345	73,700	15,900	62
February	Alternate, except 1st–22d	10	3.4	11.8	11,500	106	21,200	2,840	126
March	Alternate	14	4.2	7.2	633	31	11,100	800	34
April	Alternate, except 9th	12	14.4	6.4	280	47	3,510	1,120	98
May	Alternate	12	18.3	6.6	607	724	39,600	17,500	115
June	Alternate, except 16th	12	21.9	7.8	1,310	311	12,200	3,800	62
July	Alternate, except 5th	12		7.9	1,540	657	21,300	15,900	114
August	Alternate	13		8.5	2,060	576	33,100	44,200	232
September	Alternate, except 6th, 20th, 27th.	10		8.3	2,600	193	20,100	15,600	262
October	Alternate	13		7.6	1,330	136	18,000	10,700	189
November	do	13		7.1	910	71	31,700	16,500	42
December	Alternate, 1st–15th, also 20th, 22d, 27th, 31st.	11		9.2	7,180	70	30,900	10,500	121
1916									
January	Alternate	12		12.5	11,900	328	50,300	7,600	51
February	do	12		9.3	3,410	114	18,800	4,000	32
March	do	13		10.5	6,280	495	52,200	15,400	44
April	do	13		9.4	4,080	64	5,300	9,600	42
May	do	12		7.9	1,840	114	7,700	3,100	30
June	Alternate, except 17th	12		8.4	1,900	242	22,600	13,800	205
July	Alternate	13		6.6	337	163	5,200	3,200	113
August	Alternate, except 21st	12		6.4	283	295	24,700	16,600	342
September	Alternate, except 6th	11		6.1	298	195	25,000	16,900	213
October	Alternate	12		5.8	120	32	6,700	5,800	122
November	do	12		5.7	102	24	16,500	5,810	219
December	Alternate, except 15th, 18th, 20th, 22d, 27th.	7		7.3	1,690	193	78,000	16,700	190

[1] Exclusive of result on a single day, August 28th, average for months would be 127, which is a more probable figure.

TABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION, LICKING RIVER AT LOUISVILLE & NASHVILLE RAILROAD BRIDGE, LATONIA, KY., ABOUT 3 MILES ABOVE MOUTH

[River stages at U. S. Weather Bureau gage, Falmouth, Ky]

Months	Dates of sample collections	Total days samples taken	Monthly means						
			Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C., 48 hours	Bacteria per c. c. on— Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
January	Daily, 5th–31st, except 20th.	23	3.2	3.7	3,370	189	18,100	1,960	35
February	Daily, 2d–13th, except 7th, also 24th, 25th 28th.	13	3.8	8.1	13,200	381	24,500	1,840	44
March	Daily, except 1st–3d, 13th, 14, 17th–19th, 28th.	18	5.4	5.5	6,830	215	15,500	2,100	12
April	Daily, except 2d, 7th, 18th.	23	13.2	5.0	5,670	188	3,830	1,370	28
May	Daily, except 30th	25	19.4	3.9	4,000	206	4,890	2,600	51
June	Five days weekly, except 6th, 9th.	19	27.6	2.0	1,030	391	14,100	[1] 8,900	218
July	Daily, except 2d, 4th, 20th, 23d.	23	29.3	1.2	110	63	4,770	4,320	280
August	Daily, except 13th, 20th, 29th.	23	27.2	1.8	740	458	[2] 10,800	9,700	366
September	Daily, except 1st, 7th, 9th, 16th, 23d, 30th.	20	22.5	1.4	230	340	3,680	4,600	307
October	1st–14th, except 7th, 8th	10	19.3	1.7	960	178	8,220	8,630	334
Do	Daily, except 7th, 8th, 15th–17th, 22d, 28th.	20	16.6	3.2	3,600	201	4,950	5,550	190
November	Daily, except 9th, 12th 14th, 17th, 19th, 20th, 24th, 26th.	17	7.6	1.5	228	42	8,370	2,080	211
December	Daily, except 1st, 14th, 16th, 21st, 22d, 25th, 28th 30th.	19	------	5.2	6,100	275	16,700	13,950	152
1915									
January	Daily, except 27th	24	------	6.7	9,260	299	20,400	7,760	91
February	Daily, except 1st, 2d, 22d.	21	------	6.8	10,640	124	14,100	2,140	19
March	Daily	27	------	4.1	4,210	148	6,710	1,040	27
April	do	26	------	2.5	1,360	161	1,650	417	15
May	Daily, except 31st	25	------	4.2	4,500	1,760	22,300	14,900	290
June	Daily	26	------	4.0	3,960	1,450	16,700	14,200	293
July	Daily, except 5th	26	------	5.4	7,370	982	24,100	16,700	618
August	Daily	26	------	3.2	2,580	660	21,500	14,000	252
September	Daily, except 6th	25	------	2.3	1,260	206	14,600	12,900	139
October	Daily	26	------	3.3	2,860	124	6,900	4,000	117
November	Daily, except 25th	25	------	3.8	4,430	135	15,100	9,340	280
December	Daily, except 24th, 25th	25	------	9.4	16,840	225	17,500	5,400	124
1916									
January	Daily	24	------	9.9	18,600	477	32,900	4,800	85
February	do	22	------	8.1	12,540	300	22,600	3,600	43
March	Alternate days	14	------	7.7	9,890	448	25,100	5,200	49
April	do	12	------	4.3	5,374	72	5,000	1,400	38
May	do	14	------	2.8	2,226	121	5,400	2,200	33
June	do	13	------	5.2	6,233	485	13,000	7,500	183
July	Alternate days, except 7th.	11	------	1.9	797	95	4,344	2,400	51
August	Alternate days	13	------	3.0	2,194	895	12,400	10,800	287
September	do	12	------	1.8	994	481	16,200	9,600	220
October	do	13	------	1.7	704	243	24,100	23,700	135
November	do	13	------	1.6	340	99	2,800	2,000	99
December	do	12	------	4.8	5,644	428	26,600	9,500	122

[1] Excessive agar count (225,000) of June 1 excluded from average. Including this result, average for month would be 19,700.

[2] Excessive gelatin count (342,000) of Aug. 4 omitted. Inclusive of this result, average for month would be 25,800.

[3] Exclusive of result on one day, July 3, average for month would be 234, which is a more probable figure.

TABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION (474)475—OHIO RIVER IMMEDIATELY BELOW CINCINNATI

[River stages at Dam 37, lower gage. Gage heights designated (*) indicate that dam was raised during a part or whole of month, forming pool above]

Months	Dates of sample collections	Total days samples taken	Monthly means: Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
January	Daily, except 30th	25	2. 1	17. 3	99, 700	106	26, 600	3, 080	131
February	Daily, except 7th, 12th, 16th, 20th, 23d, 26th, 27th.	14	2. 8	25. 3	173, 000	245	20, 850	1, 820	166
March	Daily, except 2d, 3d, 13th, 14th, 17th, 18th, 28th.	19	3. 3	24. 0	160, 000	174	22, 700	3, 480	136
April	Daily, except 2d	25	10. 5	32. 7	248, 000	171	11, 600	4, 350	135
May	Daily, except 30th	25	17. 1	19. 9	126, 000	160	16, 000	28, 000	188
June	Daily, except 4th, 9th, 18th, 25th.	22	26. 2	*5. 3	21, 000	127	121, 000	237, 000	2, 930
July	Daily, except 2d, 4th, 20th, 23d.	23	27. 3	*4. 9	19, 000	25	100, 700	147, 000	6, 190
August	Daily	26	26. 3	*3. 7	15, 200	199	[1]131,000	262, 000	9, 410
September	Daily, except 7th	24	22. 6	*4. 4	17, 500	94	95, 700	170, 000	5, 190
October	1st–15th daily	13	20. 6	*1. 2	8, 410	28	177, 000	350, 000	7, 230
October	Daily	27	17. 8	*3. 7	16, 900	163	116, 000	203, 000	3, 970
November	Daily, except 16th, 17th, 26th.	22	8. 3	*2. 8	11, 800	17	248, 000	198, 000	3, 150
December	Daily, 1st–19th, and 30th	18	4. 7	15. 2	88, 200	337	52, 700	25, 700	923
1915									
January	Daily	25	1. 5	26. 2	183, 800	244	14, 900	3, 120	144
February	Daily, except 1st, 2d, 6th, 8th, 11th, 22d.	18	3. 3	31. 9	245, 100	143	13, 800	1, 820	186
March	Daily	27	4. 5	15. 4	84, 200	90	12, 350	2, 480	363
April	do	26	12. 4	*9. 6	41, 600	26	68, 400	64, 100	1, 090
May	Daily, except 31st	25	18. 8	*11. 3	56, 000	324	57, 400	54, 700	1, 730
June	Daily	26	22. 3	*13. 9	74, 800	413	23, 700	27, 800	1, 320
July	Daily, except 5th	26	24. 9	*14. 2	75, 200	642	45, 900	57, 300	3, 300
August	Daily	26	24. 1	*11. 6	54, 800	273	43, 200	51, 900	1, 800
September	Daily, except 6th	25	22. 5	*10. 3	52, 100	174	44, 900	60, 300	1, 380
October	Daily	26	16. 6	*13. 0	70, 400	169	42, 300	39, 200	567
November	Daily, except 19th, 25th	24	10. 4	*11. 0	58, 600	96	97, 100	72, 700	819
December	Daily, except 23d, 24th, 25th.	24	3. 1	21. 4	149, 000	211	27, 200	5, 930	270
1916									
January	Daily	24	3. 7	37. 8	304, 000	277	25, 200	3, 800	117
February	do	23	3. 8	30. 3	220, 000	234	14, 300	3, 300	125
March	Alternate days	13	4. 5	28. 4	205, 000	397	28, 200	4, 000	55
April	do	12	9. 9	28. 5	207, 000	105	11, 100	4, 600	118
May	do	14	17. 7	16. 9	96, 800	146	26, 000	27, 500	601
June	do	13	21. 0	18. 4	109, 000	339	19, 800	27, 200	617
July	do	13	26. 3	*10. 1	47, 200	222	64, 700	86, 700	1, 037
August	do	13	26. 1	*9. 8	45, 600	503	47, 400	74, 200	1, 313
September	do	12	22. 2	*4. 8	18, 700	65	170, 100	151, 900	2, 300
October	do	12	15. 6	*5. 6	24, 200	78	194, 400	216, 100	5, 689
November	do	13	9. 3	*4. 7	18, 200	18	144, 800	102, 200	4, 710
December	do	7	4. 0	*12. 1	63, 600	153	34, 600	12, 300	317

[1] Excessive gelatin count (5,500,000) of Aug. 4 omitted. Inclusive of this result, average for month would be 341,000.

TABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION 482—OHIO RIVER, ½ MILE BELOW DAM NO. 37 (FERNBANK)

[River stages at Dam 37, lower gage. Gage heights designated (*) indicate that dam was raised during a part or whole of the month forming pool above]

Months	Dates of sample collections	Total days samples taken	Monthly means						
			Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Bacteria per c. c. on—		B. Coli per c. c. (est.)
							Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	
1914									
January	Daily, except 20th	25	2.1	17.3	99,700	97	19,800	1,560	65
February	Daily, except 7th, 12th, 16th–20th, 23d, 26th, 27th.	14	2.6	25.3	173,000	250	20,900	1,750	104
March	Daily, except 2d, 3d, 13th, 14th, 17th, 18th, 28th.	19	3.2	24.0	160,000	176	21,700	[1] 1,570	114
April	Daily, except 2d	25	10.3	32.7	248,000	160	10,600	5,000	182
May	Daily, except 30th	25	17.1	19.9	126,000	174	17,700	20,200	251
June	Daily, except 4th, 11th, 25th.	23	25.8	*5.3	21,000	102	67,500	91,800	1,220
July	Daily, except 2d, 4th, 20th, 23d, 30th.	22	26.8	*4.9	19,000	23	57,900	82,700	2,420
August	Daily, except 6th, 13th, 20th.	23	25.8	*3.7	15,200	173	21,000	41,100	1,120
September	Daily, except 1st, 7th, 9th, 16th, 23d, 30th.	20	22.5	*4.4	17,500	84	27,400	70,700	2,590
October	Daily, 1st–15th, except 7th, 14th.	11	18.5	*1.2	8,410	25	15,700	27,400	455
October	Daily, except 7th, 14th, 16th, 21st, 30th.	22	17.9	*3.7	16,900	100	38,400	48,900	1,500
November	Daily, except 13th, 16th, 17th, 20th, 26th.	20	8.3	*2.8	11,800	16	102,000	67,700	1,480
December	Daily, 1st–19th, except 2d, and 30th.	17	4.6	15.2	88,200	369	44,600	14,800	177
1915									
January	Daily, except 28th	24	1.5	26.2	183,800	258	14,700	2,640	114
February	Daily, except 1st, 2d, 6th, 11th, 22d.	19	3.2	31.9	245,100	152	12,900	1,550	139
March	Daily	27	4.5	15.4	84,200	87	8,580	1,160	65
April	do	26	12.3	*9.6	41,600	27	59,100	53,300	868
May	Daily, except 31st	25	18.7	*11.3	56,000	276	49,600	54,100	1,860
June	Daily	26	22.3	*13.9	74,800	427	25,300	24,900	1,440
July	Daily, except 5th	26	25.0	*14.2	75,200	605	33,800	37,700	1,760
August	Daily, except 4th	25	24.0	*11.6	54,800	280	35,300	35,400	1,100
September	Daily, except 6th	25	22.6	*10.3	52,100	177	50,100	56,700	1,850
October	Daily	26	16.5	*13.0	70,400	174	76,400	70,900	1,320
November	Daily, except 19th, 25th	24	10.2	*11.0	58,600	92	121,000	88,700	1,090
December	Daily, except 24th, 25th	25	3.0	21.4	149,000	210	25,500	4,220	111
1916									
January	Daily	24	3.5	37.8	304,000	288	25,800	3,900	112
February	do	24	2.7	30.3	220,000	238	13,800	2,900	123
March	Alternate days	14	4.3	28.4	205,000	391	27,100	3,700	132
April	do	12	9.9	28.5	207,000	107	11,500	5,200	78
May	do	14	17.5	16.9	96,800	137	29,200	30,400	586
June	do	13	21.0	18.4	109,000	357	18,800	20,100	326
July	do	13	26.2	*10.1	47,200	221	48,600	63,600	742
August	do	13	26.0	*9.8	45,600	453	61,200	97,350	2,097
September	do	12	22.0	*4.8	18,700	47	114,000	142,200	3,100
October	do	12	15.5	*5.6	24,200	79	96,000	98,100	4,797
November	do	13	9.0	*4.7	18,200	16	178,250	118,700	1,595
December	Alternate 1st–18th, and 29th.	8	4.1	*12.1	63,600	158	25,800	8,640	139

[1] Excessive agar count (45,800) of Mar. 27 omitted. Including this result, average for month would be 4,020.

ABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION 488—OHIO RIVER JUST ABOVE MOUTH OF MIAMI RIVER

iver stages at Dam No. 37, lower gage. Gage heights designated (*) indicate that dam was raised during a part or whole of the month, forming pool above]

Months	Dates of sample collections	Total days samples taken	Monthly means				Bacteria per c. c. on—		
			Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
pril	Alternate, 7th–30th	11	10. 9	32. 7	248, 000	129	10, 300	4, 940	67
lay	Alternate, except 30th	12	17. 0	19. 9	126, 000	172	22, 000	24, 900	375
ıne	Twice weekly	9	25. 6	*5. 3	21, 000	63	54, 000	50, 800	1, 330
ıly	Alternate, 7th–28th, except 23d.	9	27. 2	*4. 9	19, 000	26	19, 700	29, 900	1, 770
ugust	Twice weekly, plus 27th	10	25. 9	*3. 7	15, 200	125	15, 300	29, 800	393
eptember	Alternate, 3d–26th	11	22. 3	*4. 4	17, 500	86	21, 000	50, 800	2, 550
ctober	Alternate, 1st–15th	7	20. 1	*1. 2	8, 410	27	9, 810	10, 500	309
ctober	Alternate	14	17. 4	*3. 7	16, 900	121	27, 300	27, 900	929
ovember	Alternate, except 17th–26th	10	8. 6	*2. 8	11, 800	13	129, 300	79, 300	1, 600
ecember	Daily, 1st–19th, except 2d, 9th, 16th.	14	4. 9	15. 2	88, 200	323	84, 900	45, 400	162
1915									
anuary	Daily, except Wednesday	20	1. 4	26. 2	183, 800	268	16, 300	2, 630	111
ebruary	Daily, except Wednesday and 1st, 2d, 6th, 11th.	15	3. 2	31. 9	245, 100	138	12, 400	1, 250	70
larch	Daily, except Wednesday	22	4. 5	15. 4	84, 200	93	9, 520	1, 470	70
pril	do	22	12. 0	*9. 6	41, 600	26	87, 300	78, 400	946
lay	Daily, except Wednedsay and 31st.	21	19. 0	*11. 3	56, 000	310	51, 200	58, 400	1, 230
une	Daily, except Wednesday	22	22. 3	*13. 9	74, 800	430	33, 100	35, 900	1, 200
uly	Daily, except Wednesday and 5th.	22	25. 0	*14. 2	75, 200	632	40, 000	42, 200	1, 470
ugust	Daily, except Wednesday	22	23. 9	*11. 6	54, 800	261	64, 800	54, 500	1, 180
eptember	Daily, except Wednesday and 5th.	20	22. 6	*10. 3	52, 100	163	48, 200	54, 900	1, 330
)ctober	Daily, except 6th, 13th	24	16. 6	*13. 0	70, 400	164	90, 400	69, 600	1, 860
Iovember	Daily, except 19th, 25th	24	10. 2	*11. 0	58, 600	93	83, 200	61, 100	815
)ecember	Daily, except 24th	25	2. 9	21. 4	149, 000	198	22, 800	4, 180	151
1916									
anuary	Daily, except 17th	24	3. 5	37. 8	304, 000	284	27, 000	3, 620	125
'ebruary	Daily	24	2. 8	30. 3	220, 000	240	14, 000	2, 850	92
larch	Alternate, except 22d	13	4. 3	28. 4	205, 000	429	27, 400	3, 600	74
april	do	12	9. 9	28. 5	207, 000	107	11, 600	5, 280	102
lay	do	14	17. 5	16. 9	96, 800	139	43, 800	37, 200	546
une	do	13	20. 9	18. 4	109, 000	326	30, 300	28, 200	340
uly	do	13	26. 1	*10. 1	47, 200	227	43, 400	60, 000	767
ugust	do	13	25. 9	*9. 8	45, 600	363	57, 200	83, 500	1, 880
eptember	do	12	23. 7	*4. 8	18, 700	43	46, 100	49, 000	1, 470
)ctober	Alternate, except 20th	12	15. 2	*5. 6	24, 200	73	57, 600	54, 100	1, 750
Iovember	do	13	8. 9	*4. 7	18, 200	16	190, 000	118, 000	3, 050
)ecember	Alternate, except 13th, 20th, 22d, 27th.	8	3. 9	*12. 1	63, 600	174	34, 700	9, 680	230

TABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION, MIAMI RIVER—AT MOUTH, IN MIDSTREAM

[Gage heights at Hamilton, Ohio, during 1914, at U. S. Geological Survey Gage (lower), thereafter at U. S. P. H. S. Gage (upper)]

Months	Dates of sample collections	Total days samples taken	Monthly means: Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C., 48 hours	Bacteria per c. c. on— Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
April	Alternate, 7th–30th	11	12.0	5.4	14,300	78	19,700	4,480	131
May	Alternate, 2d–26th	11	17.5	3.5	4,430	109	15,400	2,790	33
June	Twice weekly, 9th–30th	7	25.6	2.6	1,240	74	1,380	933	2
July	Alternate, 7th–28th, except 14th–23d.	8	25.4	2.5	1,000	233	3,080	3,030	153
August	Twice weekly, plus 27th	10	23.7	2.5	1,270	565	11,700	11,100	215
September	Alternate, 8th–26th	9	19.5	2.4	840	72	1,070	1,690	125
October	Alternate days, 1st–15th	7	18.3	2.1	650	54	1,320	1,490	10
Do	Alternate	14	16.1	2.5	1,240	63	2,650	1,820	22
November	Alternate, except 17th, 26th	10	7.3	2.2	782	23	6,120	1,570	14
December	Daily, except Wednesday (1st–21st).	15	4.2	2.8	2,160	37	14,000	7,800	255
1915									
January	Daily, except Wednesday	21	1.0	4.3	3,890	196	53,200	13,000	297
February	Daily, except Wednesday and 1st, 2d, 22d.	17	4.1	6.4	17,760	124	37,500	8,000	232
March	Daily, except Wednesday	22	5.2	4.1	3,030	39	11,500	2,370	33
April	do	22	14.4	3.7	1,900	41	6,380	2,300	13
May	do	21	17.8	3.9	2,840	129	5,730	3,240	28
June	Daily, except Wednesday and 5th.	21	22.2	4.4	4,230	446	10,300	10,970	203
July	do	22	23.6	5.6	11,300	992	28,000	17,200	410
August	Daily, except Wednesday	22	21.9	4.7	5,440	444	54,400	28,700	791
September	Daily, except Wednesday and 6th.	20	20.8	4.8	6,400	145	21,400	14,200	306
October	Daily, except 6th, 13th	24	15.3	4.4	4,630	118	23,800	8,370	212
November	Daily, except 19th, 25th	24	8.8	4.1	3,410	44	23,900	15,700	213
December	Daily, except 24th, 25th	25	2.3	4.8	6,580	153	40,000	9,500	118
1916									
January	Daily	24	3.7	7.7	28,240	432	85,800	16,400	233
February	do	23	2.8	5.7	13,480	167	28,000	11,300	323
March	Alternate days	14	5.5	6.0	13,620	337	51,500	13,300	260
April	do	12	11.1	5.1	7,430	206	31,700	6,000	115
May	do	14	17.5	5.1	8,064	205	19,300	9,800	183
June	do	13	20.5	5.2	8,592	323	19,100	14,200	128
July	do	13	25.6	3.5	1,450	97	1,900	2,200	20
August	do	13	24.5	3.4	1,016	438	16,400	11,100	167
September	do	12	19.5	3.4	1.102	71	11,600	3,800	15
October	Alternate, except 20th	12	13.6	3.2	666	12	1,600	1,900	38
November	Alternate days	13	7.6	3.2	562	11	26,600	2,900	21
December	Alternate days, except 13th, 22d.	7	4.2	3.4	1,425	49	35,600	5,200	34

ABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

AMPLING STATION 492—OHIO RIVER, 3 MILES BELOW MOUTH OF MIAMI RIVER

iver stages at Dam No. 37, lower gage. Gage heights designated (*) indicate that dam was raised during a part or whole of the month, forming pool above]

Months	Dates of sample collections	Total days samples taken	Monthly means: Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C., 48 hours	Bacteria per c. c. on— Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
pril	Alternate, 7th–30th	11	10.5	32.7	262,300	148	13,000	7,440	83
lay	Alternate	12	16.9	19.9	130,400	186	7,130	39,500	328
une	Twice weekly	9	25.0	*5.3	22,200	47	41,600	48,900	530
uly	Alternate, 7th–28th, except 23d.	9	26.5	*4.9	20,000	95	18,600	23,900	2,290
ugust	Twice weekly, plus 27th	10	25.0	*3.7	16,500	130	17,600	39,600	807
eptember	Alternate, 3d–26th	11	22.0	*4.4	18,300	92	16,400	40,600	2,390
ctober	Alternate, 8th–15th	4	20.0	*1.2	9,060	25	4,440	6,130	92
Do	Alternate, 8th–29th	10	17.1	*3.7	18,100	172	24,000	24,500	390
ovember	Alternate, 5th–28th, except 17th, 24th, 26th.	8	8.5	*2.8	12,600	12	140,000	85,100	617
ecember	Daily, except Wednesday (1st–21st).	15	4.6	15.2	90,400	301	80,200	37,400	296
1915									
anuary	Daily, except Wednesday	21	1.3	26.2	187,700	266	18,400	3,820	121
ebruary	Daily, except Wednesday and 22d.	17	3.2	31.9	262,900	143	16,000	2,040	227
larch	Daily, except Wednesday	22	4.4	15.4	87,200	82	9,110	2,010	84
pril	do	22	11.9	*9.6	43,500	28	76,700	67,700	660
lay	do	21	18.8	*11.3	58,800	328	43,800	47,500	1,680
une	do	22	22.3	*13.9	79,000	387	34,100	34,400	1,580
uly	Daily, except Wednesday and 5th.	22	24.9	*14.2	86,500	751	43,800	39,800	1,400
ugust	Daily, except Wednesday	22	23.9	*11.6	60,200	332	73,500	64,200	1,570
eptember	Daily, except Wednesday and 6th.	20	22.3	*10.3	58,400	185	42,200	44,600	1,120
ctober	Daily, except 6th, 13th	24	16.5	*13.0	75,000	175	61,900	43,400	1,230
ovember	Daily, except 19th, 20th, 25th.	23	10.3	*11.0	62,000	79	72,700	53,500	905
ecember	Daily, except 24th, 25th	25	2.8	21.4	155,600	198	25,000	4,870	239
1916									
anuary	Daily	24	3.5	37.8	332,240	315	34,500	4,800	146
ebruary	do	23	3.5	30.3	233,480	257	15,600	3,300	78
larch	Alternate days	14	4.1	28.4	218,620	411	29,400	4,400	91
pril	do	12	9.8	28.5	214,430	118	12,900	5,800	160
lay	do	14	17.5	16.9	104,864	163	41,600	37,600	387
une	do	13	20.8	18.4	117,592	321	35,500	32,600	688
uly	do	13	26.0	*10.1	48,850	209	36,300	55,900	783
ugust	do	13	25.7	*9.8	46,616	361	49,100	72,800	2,061
eptember	do	12	21.3	*4.8	19,802	48	46,500	39,600	900
ctober	do	12	14.9	*5.6	24,866	69	51,900	49,000	1,375
ovember	do	13	8.7	*4.7	18,762	16	204,500	115,500	2,836
ecember	Alternate days except 20th, 22d, 27th.	9	3.9	*12.1	65,025	160	33,500	10,800	293

TABLE NO. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION 543—OHIO RIVER AT CARROLLTON, KY., IMMEDIATELY ABOVE MOUTH OF KENTUCKY RIVER

[River stages at Dam No. 37, lower gage (below Cincinnati). Sample collections begun Aug. 7, 1914. Samples were iced and shipped by express to Cincinnati for examination. Ordinarily received within 6 to 8 hours. Samples discarded when delayed in transit. Bacteriological results for this station are generally less reliable than for other stations, owing to less prompt examination of samples]

Months	Dates of sample collections	Total days samples taken	Monthly means						
			Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Bacteria per c. c. on—		B. Coli per c. c. (est.)
							Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	
1914									
August [1]	Twice weekly, 7th-31st	8	------	*3.7	16,700	--------	1,700	2,860	33
September	Twice weekly	8	------	*4.4	18,600	116	5,330	8,900	103
October	Twice weekly, 1st-15th	5	------	*1.2	---------	7	530	544	2
Do	Twice weekly	9	------	*3.7	18,400	98	4,950	3,800	36
November	Twice weekly, except 26th	8	------	*2.8	12,800	16	[1] 3,900	3,150	43
December	Twice weekly, except 24th	8	------	15.2	91,800	288	26,000	13,200	175
1915									
January	Twice weekly	8	------	26.2	190,500	206	17,200	2,280	182
February	do	8	------	31.9	266,800	189	25,400	2,360	96
March	do	8	------	15.4	88,500	104	8,960	1,370	85
April	do	9	------	*9.6	44,200	16	11,100	10,300	239
May	do	8	------	*11.3	59,700	236	28,100	32,000	770
June	do	9	------	*13.9	80,200	374	16,800	15,000	296
July	do	9	------	*14.2	87,800	410	100,000	58,900	496
August	do	9	------	*11.6	61,100	257	78,300	47,700	344
September	Twice weekly, except 20th	8	------	*10.3	59,300	201	96,400	82,900	958
October	Twice weekly	8	------	*13.0	76,100	153	21,300	13,900	159
November	Twice weekly, except 29th	8	------	*11.0	62,900	115	39,300	27,000	338
December	Twice weekly	9	------	21.4	157,900	178	21,300	4,030	156
1916									
January	Alternate days	9	------	37.8	337,200	364	38.400	6,500	70
February	Every fourth day	8	------	30.3	237,000	249	15,900	3,600	141
March	do	9	------	28.4	221,900	276	23,300	3,400	102
April	Every third day	8	------	28.5	217,600	92	21,200	4,800	38
May	Every fourth day, except 25th.	9	------	16.9	106,400	104	19,100	18,400	233
June	Every third day	9	------	18.4	119,400	340	27,310	19,400	280
July	Every third day, except 24th, 31st.	9	------	*10.1	49,380	103	18,800	31,100	164
August	Every fourth day, except 10th, 31st.	8	------	*9.8	47,320	232	15,900	20,400	276
September	Every third day, except 7th, 18th, 25th.	8	------	*4.8	20,100	29	18,200	11,200	35
October	Every fourth day	9	------	*5.6	25,230	32	10,200	8,100	189
November	Every fourth day, except 9th.	8	------	*4.7	19,040	18	45,300	18,100	925
December	Every third day	9	------	*12.1	66,000	127	22,200	6,200	57

[1] Excessive gelatin count (71,900) of Nov. 30 omitted. Including this result, average for month would be 12,400.

'ABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION, KENTUCKY RIVER, AT MOUTH, CARROLLTON, KY.

Jage heights at lower gage. Lock No. 4, Frankfort, Ky. Date of establishing station and arrangements for examination of samples the same as at station No. 543. See note Table A-30]

Months	Dates of sample collections	Total days samples taken	Monthly means						
			Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Bacteria per c. c. on—		B. Coli per c. c. (est.)
							Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	
1914									
ugust	Twice weekly, 13th-31st	6	------	6.7	1,150	--------	1,310	1,800	17
eptember	Twice weekly, except 11th	7	------	6.9	1,530	132	860	2,630	3
ctober	Twice weekly, 1st-15th	5	------	6.8	1,220	14	238	369	1
Do	Twice weekly	9	------	7.5	3,850	163	550	1,340	25
ovember	Twice weekly, except 26th	8	------	6.4	343	37	628	322	13
ecember	Twice weekly, except 24th	8	------	8.6	7,320	337	15,500	4,590	55
1915									
anuary	Twice weekly	8	------	10.2	13,200	240	8,400	1,980	44
ebruary	-----do	8	------	9.8	12,300	210	17,700	2,330	141
Iarch	-----do	8	------	8.6	7,020	94	20,000	3,240	140
pril	-----do	9	------	7.3	2,740	28	[1] 900	343	1
Iay	-----do	8	------	7.5	3,760	88	3,240	3,590	27
une	-----do	9	------	8.1	5,420	477	35,000	29,700	139
uly	-----do	9	------	9.3	9,450	968	86,700	50,900	168
ugust	-----do	9	------	7.8	4,280	359	55,400	44,700	139
eptember	Twice weekly, except 20th	8	------	7.1	2,260	254	56,000	50,000	425
ctober	Twice weekly	8	------	8.1	5,300	197	13,700	9,760	42
ovember	Twice weekly, except 29th	8	------	8.3	7,060	173	9,280	5,720	63
ecember	Twice weekly	9	------	14.9	34,000	319	24,400	6,050	149
1916									
anuary	Every third day	9	------	12.2	24,200	599	43,200	6,800	30
ebruary	-----do	8	------	10.0	12,120	212	15,100	2,700	32
Iarch	-----do	9	------	9.9	11,010	232	12,100	3,800	157
pril	Every third day, except 24th.	8	------	8.6	7,014	95	16,800	8,900	18
Iay	Every third day; 25th sample broken.	8	------	7.3	2,842	25	25,300	16,900	18
une	Every third day; 12th sample broken.	8	------	7.7	3,674	274	45,100	33,000	49
uly	Every third day, except 6th, 27th.	9	------	6.9	1,651	151	131,300	117,700	352
ugust	Every fourth day, except 10th.	8	------	7.5	4,122	305	26,900	13,300	36
eptember	Every third day	8	------	6.6	959	124	44,000	45,500	16
ctober	Every fourth day, except 16th.	8	------	6.7	1,613	43	28,600	17,000	6
November	Every fourth day	8	------	6.4	383	27	10,100	3,400	28
December	Every third day	8	------	7.5	5,440	357	60,200	6,700	6

[1] Excessive gelatin count (30,000) of Apr. 9 omitted.

TABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION 598—OHIO RIVER IMMEDIATELY ABOVE LOUISVILLE, OPPOSITE INTAKE FOR WATERWORKS

[River stages at lower gage, Dam No. 41]

Months	Dates of sample collections	Total days samples taken	Monthly means				Bacteria per c. c. on—		
			Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
January	Daily, 8th–30th, except 12th, 19th, 22d, 24th, 29th.	15	2.0	17.6	108,000	76	-------	[1] 2,730	31
February [2]	3d, 4th, 6th, 7th, 24th, 25th	6	3.2	29.1	221.000	435	22,800	4,900	85
March	Daily, 5th–31st, except 6th, 11th, 16th, 18th, 21st, 23d, 28th.	14	3.5	26.4	192,000	252	16,700	2,780	32
April	Daily, except 3d–12th, 25th, 29th.	16	10.3	36.0	297,000	167	3,830	3,250	109
May	Daily, except 8th–12th, 23rd.	20	17.6	21.4	147,000	145	3,050	2,780	97
June	Daily	26	25.3	6.9	28,800	60	648	586	11
July	Daily, 1st–29th, except 4th	24	27.0	6.0	23,100	7	292	203	1
August	Daily, except 10th, 24th	24	26.0	5.1	18,300	24	2,140	1,250	102
September	Daily, except 7th, 9th, 22d	23	22.9	5.5	20,900	118	1,280	506	20
October	Daily, 1st–15th	13	19.6	2.9	7,510	6	215	318	4
do	Daily	27	18.0	5.5	22,400	73	1,040	700	11
November	Daily, except 26th	24	10.0	3.9	12,300	11	206	124	4
December	Daily, except 9th, 25th, 26th, 30th, 31st.	22	4.0	15.6	96,500	214	9,990	2,400	30
1915									
January	Daily, 4th–30th	24	1.6	29.1	221,600	267	13,800	2,780	36
February	Daily, except 22d, 28th	23	3.0	36.4	309,100	256	18,900	2,240	47
March	Daily	27	4.7	16.4	98,800	86	5,040	543	16
April	do	26	12.8	10.0	48,300	12	935	220	3
May	Daily, except 31st	25	19.2	11.5	63,800	171	4,790	3,450	47
June	Daily	26	22.9	15.8	94,100	246	3,540	3,220	56
July	Daily, except 5th	26	25.6	16.8	102,500	314	4,510	4,500	102
August	Daily	26	24.3	12.4	66,400	157	3,730	2,810	56
September	Daily, except 6th	25	22.6	11.7	61,200	114	2,900	2,880	71
October	Daily	26	16.5	14.3	85,100	146	4,600	3,070	65
November	Daily, except 25th	25	10.5	12.6	72,500	118	7,120	3,360	44
December	Daily	26	3.3	25.4	201,000	293	30,100	4,870	56
1916									
January	Daily	25	4.2	44.2	401,000	364	35,500	4,800	69
February	do	24	3.6	35.2	287,000	332	29,200	4,200	107
March	do	26	4.8	30.6	233,000	451	32,200	4,000	78
April	do	25	10.9	31.7	258,000	151	9,900	2,000	29
May	do	26	18.6	17.7	114,000	130	6,300	2,800	61
June	do	26	21.4	18.9	126,000	357	12,200	4,800	123
July	Alternate days	12	27.7	11.1	61,400	88	3,600	4,100	36
August	do	14	28.7	11.0	58,000	216	2,700	5,100	113
September	do	13	24.6	6.5	25,900	24	700	800	10
October	do	13	17.9	6.8	27,800	33	833	800	6
November	do	13	12.6	5.7	21,400	18	2,500	800	37
December	Alternate except 19th, 21st, 23d, 26th.	9	7.7	14.1	71,000	235	25,400	4,500	72

[1] Irregular and incomplete agar counts of Jan. 15 excluded from average. Including these results average would be 3,400.

[2] Owing to severe weather and accidents interfering with boat service samples were taken at this station on only six days during February.

TABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION 611—OHIO RIVER IMMEDIATELY BELOW LOUISVILLE METROPOLITAN DISTRICT

[River stage refers to 7 a. m. readings at lower gage, Dam, No. 41, Louisville]

Months	Dates of sample collections	Total days samples taken	Monthly means: Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
January	Daily, except 3d, 5th, 7th, 14th, 19th, 26th, 31st.	19	2.1	17.6	108,000	98	--------	3,200	180
February	Daily, 6th–7th, except 7th, 10th, 13th, 14th, 16th, 19th, 23d, 25th.	11	1.2	29.1	221,000	400	26,400	5,030	165
March	Daily, except 2d, 6th, 11th–14th, 19th–21st, 24th, 28th, 29th.	15	3.7	26.4	192,000	257	22,200	3,630	128
April	Daily, except 7th, 8th, 29th.	23	10.5	36.0	297,000	215	8,030	2,860	133
May	Daily, except 8th, 9th, 12th, 23d, 30th.	21	18.0	21.4	147,000	166	5,530	3,890	233
June	Daily, except 2d	25	25.9	6.9	28,800	69	15,300	26,300	255
July	Daily, except 30th	25	27.2	6.0	23,100	22	8,820	10,100	784
August	Daily, except 10th, 25th	24	27.0	5.1	18,300	34	34,500	41,000	971
September	Daily, except 7th, 22d, 28th.	23	22.9	5.5	20,900	133	30,700	30,300	709
October	Daily, 1st–15th, except 6th	12	20.8	2.9	7,510	11	78,400	96,200	1,420
Do	Daily, except 6th, 24th	25	18.1	5.5	22,400	77	[1] 46,400	55,800	798
November	Daily, except 26th	24	9.9	3.9	12,300	12	21,300	7,970	183
December	Daily, except 9th, 25th, 26th, 29th, 30th.	23	3.7	15.6	96,500	294	13,300	3,350	56
1915									
January	Daily, 4th–30th, except 7th, 18th.	22	1.5	29.1	221,600	307	14,900	3,150	52
February	Daily, except 13th, 22d, 28th.	22	3.3	36.4	309,100	269	18,200	2,290	41
March	Daily	27	4.9	16.4	98,800	100	5,540	617	23
April	Daily, except 26th, 27th	24	12.8	10.0	48,300	15	1,220	350	27

SAMPLING STATION 619—17 MILES BELOW LOUISVILLE

[River stage refers to 7 a. m. readings at lower gage, Dam No. 41, Louisville]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
March	Daily, 5th–31st, except 6th, 11th, 14th, 17th, 19th–21st, 23d, 27th, 28th	11	3.8	26.4	192,000	285	21,400	3,330	182
April	Daily, except 7th, 8th, 29th.	23	10.5	36.0	297,000	220	7,870	[2] 2,880	175
May	Daily, except 8th, 9th, 23d, 30th.	22	18.0	21.4	147,000	179	8,860	5,600	223
June	Daily, except 2d, 4th	24	25.9	6.9	28,800	71	35,850	52,100	456
July	Daily, except 4th, 30th	25	27.2	6.0	23,100	14	31,400	34,400	1,230
August	Daily, except 10th, 28th, 29th.	23	27.1	5.1	18,300	28	63,600	77,000	1,190
September	Daily, except 1st, 7th, 22d	23	22.6	5.5	20,900	119	45,400	42,600	1,380
October	Daily, 1st–15th, except 6th, 10th.	11	20.8	-------	7,510	10	44,700	71,000	1,240
Do	Daily, except 6th, 10th, 28th.	24	18.0	5.5	22,400	81	54,800	57,900	755
November	Daily, except 21st, 25th, 26th.	22	10.2	3.9	12,300	13	58,800	26,900	344
December	Daily, except 10th–15th, 25th, 26th, 30th, 31st.	18	3.6	15.6	96,500	227	15,900	3,600	141
1915									
January	Daily, 4th–30th	24	1.6	29.1	221,600	306	13,900	2,690	43
February	Daily, except 13th, 22d, 28th.	22	3.3	36.4	309,100	261	18,500	2,460	34
March	Daily	27	4.9	16.4	98,800	100	6,140	597	24
April	Daily, except 26th, 27th	24	12.8	10.0	48,300	19	8,590	3,140	63

[1] Irregular gelatin count of Oct. 16, "N" point, excluded from average.
[2] Irregular agar count of Apr. 18, "C" point excluded from average. Including this result average for the month would be 3,260.

TABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION 904—OHIO RIVER, IMMEDIATELY ABOVE MOUTH OF CUMBERLAND RIVER

[River stage U. S. Weather Bureau gage, Paducah, Ky.]

Months	Dates of sample collections	Total days samples taken	Monthly means: Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
May	Alternate, 5th–29th, except 9th, 25th.	10	19.1	18.5	210,000	211	--------	924	19
June	Alternate	13	26.9	6.0	46,600	62	--------	646	3
July	-----do	14	28.3	4.4	30,800	15	157	129	1
August	-----do	13	27.5	2.5	26,400	18	227	221	2
September	Alternate, except 7th	12	23.3	4.6	37,300	150	677	811	22
October	Alternate, 1st–15th	6	21.3	1.9	23,700	91	273	414	15

SAMPLING STATION, CUMBERLAND RIVER, AT MOUTH, IN MIDSTREAM [1]

[River stage—U. S. Weather Bureau gage, Nashville, Tenn.]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
May	Alternate, 5th–29th, except 9th, 25th.	10	20.3	12.9	25,300	235	--------	713	26
June	Alternate	13	29.4	7.9	4,540	50	--------	213	2
July	-----do	14	28.9	8.7	8,000	269	608	320	10
August	-----do	13	28.0	8.5	6,880	123	381	322	6
September	Alternate, except 7th	12	24.5	8.4	6,840	238	746	796	21
October	Alternate, 1st–15th	6	21.5	7.5	3,320	285	828	618	20

SAMPLING STATION 920—OHIO RIVER IMMEDIATELY ABOVE MOUTH OF TENNESSEE RIVER

[River stage—U. S. Weather Bureau gage, Paducah, Ky.]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
May	Daily, 5th–30th, except 6th, 8th, 16th.	20	19.5	18.5	235,300	198	--------	639	23
June	Daily, except 13th	25	26.9	6.0	51,100	46	--------	690	3
July	Daily	27	28.9	4.4	38,800	87	208	200	2
August	-----do	26	27.9	2.5	33,300	41	226	225	3
September	Daily, except 7th	25	23.7	4.6	44,200	186	593	684	24
October	Daily, 1st–15th	13	21.2	1.9	27,000	122	361	479	15

SAMPLING STATION, TENNESSEE RIVER, AT MOUTH [2]

[River stage U. S. Weather Bureau gage, Johnsonville, Tenn.]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
May	Alternate, 5th–29th, except 9th.	11	22.1	6.3	[3] 44,000	85	--------	262	5
June	Alternate	13	29.6	2.1	17,100	82	--------	[4] 130	1
July	-----do	14	29.7	2.2	19,200	90	116	164	3
August	-----do	13	28.4	2.0	16,700	60	199	174	1
September	Alternate, except 7th	12	25.0	1.5	15,900	98	292	372	4
October	Alternate, 1st–15th	6	21.6	0.4	12,300	82	358	490	5

[1] Samples from a single point, mid-depth, in midstream, near mouth.

[2] Samples were at first, during May, collected from three points laid out on a cross-section. At low stages of river south sampling point was dry, and center point at margin of stream, leaving north point at about midstream in the reduced channel. Samples as taken represent a fair average for the stream.

[3] Discharge calculated at mouth.

[4] Irregular agar count at "N" point, June 17, excluded from average. Including this result, average for month would be 260.

TABLE No. 84.—*Summary of bacteriological observations—Monthly means by stations, with related data*—Continued

SAMPLING STATION 926—OHIO RIVER, 2 MILES BELOW PADUCAH, KY.

[River stage refers to 7 a. m. readings at U. S. Weather Bureau gage, Paducah, Ky.

Months	Dates of sample collections	Total days samples taken	Monthly means: Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
May	Alternate, 6th–30th, except 16th.	10	19.8	18.5	279,300	194	--------	810	18
June	Alternate	13	27.6	6.0	68,200	43	--------	[1] 530	1
July	-----do	13	28.6	4.4	58,000	95	154	173	2
August	-----do	13	27.7	2.5	50,000	39	250	[2] 170	3
September	-----do	13	24.0	4.6	60,100	173	579	656	21
October	Alternate, 1st–15th	7	21.4	1.9	39,300	120	829	894	22

SAMPLING STATION 933—OHIO RIVER, 9 MILES BELOW PADUCAH, KY.

[River stage refers to 7 a. m. readings at U. S. Weather Bureau gage, Paducah, Ky.]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
May	Alternate, 6th–30th	11	19.8	18.5	279,300	195	--------	809	19
June	Alternate	13	28.0	6.0	68,200	37	--------	534	5
July	-----do	13	29.0	4.4	58,000	72	155	153	2
August	-----do	13	27.9	2.5	50,000	39	[3] 160	[3] 170	6
September	-----do	13	24.1	4.6	60,100	169	445	560	21
October	Alternate, 1st–15th	7	21.4	1.9	39,300	106	644	740	36

SAMPLING STATION 938—OHIO RIVER, 14 MILES BELOW PADUCAH, KY.

[River stage refers to 7 a. m. reading at U. S. Weather Bureau gage, Paducah, Ky.]

Months	Dates of sample collections	Total days samples taken	Temperature, ° C.	River stage (feet)	Discharge, (second-feet)	Turbidity (p. p. m.)	Gelatin at 20° C., 48 hours	Agar at 37° C., 24 hours	B. Coli per c. c. (est.)
1914									
May	Weekly	4	19.4	18.5	279,300	147	--------	858	14
June	-----do	4	27.7	6.0	68,200	33	--------	[4] 390	2
July	11th and 23d	2	28.7	4.4	58,000	125	--------	117	5
September	5th, 10th, and 24th	3	24.0	4.6	60,100	189	603	868	29

[1] Irregular agar count, "S" point, June 27, excluded from average. Including this result, average for month would be, 660.

[2] Irregular agar count of Aug. 11 excluded from average. Including these results, averages for month would be 350.

[3] Irregular gelatin and agar counts at "N" point, Aug. 27, excluded from average; including these results, average for month would be gelatin, 270, agar, 280.

[4] Excluding excessive agar count at one point on June 30, average for month would be 220.

TABLE No. 85.—*Summary of bacteriological observations—Monthly means at all stations by months, 1914 and 1915, with related data*

JANUARY, 1914

Sampling stations	Monthly means: Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from Pittsburgh (hours)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C.	Bacteria per c. c. on— Agar at 37° C.	B. Coli per c. c. (est.)
Allegheny No. 1	0.9	6.6	21,800		62		1,110	162
Monongahela No. 1	1.0	5.8	20,200		85		362	64
Ohio No. 1	.9	5.8	38,800		71		560	83
Ohio No. 3	1.0	5.8	38,800	2.1	89		440	86
Ohio No. 5	1.0	5.8	38,800		86		310	80
Little Scioto River	2.3				17		616	8
Ohio No. 349	2.3	18.5	90,800	148.8	60		816	21
Tygarts Creek	2.3				17		417	1
Ohio No. 352	2.3	18.5	90,800		64		904	24
Ohio No. 355	2.3	18.5	90,800	151.5	63		870	22
Scioto River	2.3	2.2	5,050		41		2,130	32
Ohio No. 358	2.3	18.5	95,800	152.7	69		1,080	18
Ohio No. 461	2.2	17.3	94,900	192.6	95	19,900	444	17
Little Miami River	2.8		1,410		171	45,800	640	19
Licking River	3.2	3.7	3,370		189	18,100	1,960	35
Ohio No. 471	2.2				112	23,600	1,540	138
Ohio No. 474	2.1	17.3	99,700	198.5	106	26,600	3,080	131
Ohio No. 482	2.1	17.3	99,700	202.1	97	19,800	1,560	65
Ohio No. 598	2.0	17.6	108,000	261.7	76		2,730	31
Ohio No. 611	2.1	17.6	108,000	269.9	98		3,200	180

FEBRUARY, 1914

Sampling stations	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from Pittsburgh (hours)	Turbidity (p. p. m.)	Gelatin at 20° C.	Agar at 37° C.	B. Coli per c. c. (est.)
Allegheny No. 1	2.4	11.3	25,600		71		1,560	207
Monongahela No. 1	2.4	6.4	18,400		62		560	104
Ohio No. 3	2.4	6.4	42,200	1.9	81		1,013	226
Ohio No. 5	2.4	6.4	42,200		78		820	177
Ohio No. 11	2.5	6.4	42,200	6.5	68		1,170	32
Little Scioto River	2.0				56	9,370	900	38
Ohio No. 348	1.9	25.1	138,000	136.0	121	12,500	993	51
Tygarts Creek	2.8				63	8,510	1,650	46
Ohio No. 352	3.0	25.1	138,000		102	16,200	1,400	45
Ohio No. 355	1.5	25.1	138,000	138.4	132	11,200	1,270	32
Scioto River	1.6	5.5	14,200		217	34,600	4,140	71
Ohio No. 358	1.7	25.1	152,200	139.4	174	14,400	1,460	48
Ohio No. 461	2.9	25.3	156,100	175.7	208	19,500	1,360	50
Little Miami River	1.1		3,680		218	53,900	5,060	62
Licking River	3.8	8.1	13,200		381	24,500	1,840	44
Ohio No. 474	2.8	25.3	173,000	180.4	245	20,850	1,820	166
Ohio No. 482	2.6	25.3	173,000	183.2	250	20,900	1,750	104
Ohio No. 598	3.2	29.1	221,000	228.7	435	22,800	4,900	85
Ohio No. 611	1.2	29.1	221,000	233.9	400	26,400	5,030	165

MARCH, 1914

Sampling stations	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from Pittsburgh (hours)	Turbidity (p. p. m.)	Gelatin at 20° C.	Agar at 37° C.	B. Coli per c. c. (est.)
Allegheny No. 7	4.7	12.8	37,000		71	7,690	640	8
Allegheny No. 1	2.3	12.8	37,000		48		1,620	246
Monongahela No. 12	3.7	7.7	23,300		55	1,370	120	8
Turtle Creek					161		543	220
Monongahela No. 1	3.8	7.7	23,300		58	4,210	780	124
Ohio No. 3	1.4	7.7	57,200	1.5	53	7,400	950	169
Ohio No. 5	2.2	7.7	57,200		61	5,810	760	179
Ohio No. 11	3.0	7.7	57,200	5.2	69	2,800	288	10
Little Scioto River	3.2				46	3,530	548	7
Ohio No. 348	3.2	24.5	133,000	124.0	115	8,200	630	19
Tygarts Creek	5.0				66	1,970	400	25
Ohio No. 355	3.2	24.5	133,000	126.5	113	8,060	745	22
Scioto River	3.2	7.2	19,100		208	22,400	3,060	37
Ohio No. 360	3.2	24.5	152,100	127.5	130	11,100	1,040	19
Ohio No. 461	3.4	24.0	147,700	162.7	155	18,900	854	20
Little Miami River	4.8		5,470		225	35,500	3,260	24
Licking River	5.4	5.5	6,830		215	15,500	2,100	12
Ohio No. 474–475	3.3	24.0	160,000	167.6	174	22,700	3,480	136
Ohio No. 482	3.2	24.0	160,000	170.6	176	21,700	1,570	114
Ohio No. 598	3.5	26.4	192,000	214.8	252	16,700	2,780	32
Ohio No. 611	3.7	26.4	192,000	220.5	257	22,200	3,630	128
Ohio No. 619	3.8	26.4	192,000	223.3	285	21,400	3,330	182

TABLE No. 85.—*Summary of bacteriological observations—Monthly means at all stations by months, 1914 and 1915, with related data*—Continued

APRIL, 1914

Sampling stations	Monthly means							
	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from Pittsburgh (hours)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C.	Bacteria per c. c. on— Agar at 37° C.	B. Coli per c. c. (est.)
Allegheny No. 7	7.3	11.6	48,100		50	2,180	400	12
Allegheny No. 1	9.2	11.6	48,100		55	4,420	1,420	114
Monongahela No. 12	10.1	11.0	32,600		53	2,230	200	12
Monongahela No. 1	10.7	11.0	32,600		68	2,670	470	26
Ohio No. 5	9.9	11.0	79,200		60	3,280	900	88
Ohio No. 19	10.3	11.0	79,200	7.8	67	2,750	500	24
Ohio No. 23	11.7	11.0	79,200	9.3	58	2,400	620	29
Beaver River	9.7		11,800		93	12,000	3,000	180
Ohio No. 29	9.6	11.0	91,000	11.3	84	5,000	934	18
Little Scioto River	11.4				69	808	735	22
Ohio No. 348	10.3	34.3	210,000	112.5	158	3,400	1,060	33
Tygarts Creek	12.0				35	1,280	540	8
Ohio No. 355	10.6	34.3	210,000	114.7	152	3,220	1,080	32
Scioto River	12.2	6.1	17,200		128	6,500	3,500	29
Ohio No. 360	10.9	34.3	227,200	115.7	163	4,000	1,310	33
Ohio No. 461	9.9	32.7	237,100	150.0	187	4,620	690	26
Little Miami River	12.7		5,160		161	17,800	2,970	42
Licking River	13.2	5.4	5,670		188	3,830	1,370	28
Ohio No. 475	10.5	32.7	248,000	154.3	171	11,600	4,350	135
Ohio No. 482	10.3	32.7	248,000	156.8	160	10,600	5,000	182
Ohio No. 488	10.9	32.7	248,000	158.7	129	10,300	4,940	67
Miami River	12.0	5.4	14,500		78	19,700	4,480	131
Ohio No. 492	10.5	32.7	262,300	160.0	148	13,000	7,440	83
Ohio No. 598	10.3	36.0	297,000	193.9	167	3,830	3,250	109
Ohio No. 611	10.5	36.0	297,000	198.6	215	8,030	2,860	133
Ohio No. 619	10.5	36.0	297,000	201.1	220	7,870	2,880	175
MAY, 1914								
Allegheny No. 7	19.3	10.2	32,800		11	5,850	6,250	15
Monongahela No. 12	23.5	6.9	8,960		12	80	41	3
Ohio No. 3	15.8	6.9	42,200	2.1	62	5,330	2,440	196
Ohio No. 11	16.0	6.9	42,200	7.2	62	2,850	1,280	76
Ohio No. 19	16.0	6.9	42,200	11.5	57	2,100	1,100	58
Ohio No. 23	16.0	6.9	42,200	13.3	64	4,100	1,780	64
Beaver River	17.7		7,480		85	6,260	3,460	235
Ohio No. 29	14.4	6.9	49,700	15.7	86	5,140	3,340	142
Ohio No. 65	16.6	11.4	55,700	28.1	82		519	39
Ohio No. 77	16.8	11.4	55,700	32.9	80		565	36
Ohio No. 88	16.8	11.4	55,700	37.2	96		447	28
Ohio No. 97	16.3	11.4	55,700	40.8	91		627	84
Ohio No. 104	16.4	11.4	55,700	44.4	73		414	72
Little Scioto River	18.2				50	456	770	22
Ohio No. 349	17.0	20.0	101,000	141.0	152	1,240	904	25
Tygarts Creek	16.9				42	487	689	26
Scioto River	18.6	2.8	6,950		158	2,500	1,810	71
Ohio No. 358	17.3	20.0	108,000	144.8	157	1,670	895	23
Ohio No. 461	17.6	19.9	120,200	183.2	138	2,450	390	19
Little Miami River	18.8		1,830		193	975	926	29
Licking River	19.4	3.9	4,000		206	4,890	2,600	51
Ohio No. 475	17.1	19.9	126,000	188.6	160	16,000	28,000	188
Ohio No. 482	17.1	19.9	126,000	191.8	174	17,700	20,200	251
Ohio No. 488	17.0	19.9	126,000	194.2	172	22,000	24,900	375
Miami River	17.5	3.5	4,430		109	15,400	2,780	33
Ohio No. 492	16.9	19.9	130,400	195.7	186	7,130	39,500	328
Ohio No. 598	17.6	21.4	147,000	243.3	145	3,050	2,780	97
Ohio No. 611	18.0	21.4	147,000	249.9	166	5,530	3,890	233
Ohio No. 619	18.0	21.4	147,000	253.0	179	8,860	5,600	223
Ohio No. 904	19.1	18.5	210,000	385.0	211		924	19
Cumberland River	20.3	12.9	25,300		235		713	26
Ohio No. 920	19.5	18.5	235,300	393.8	198		639	23
Tennessee River	22.1	6.3	44,000		85		262	5
Ohio No. 926	19.8	18.5	279,300	396.9	194		810	18
Ohio No. 933	19.8	18.5	279,300	400.8	195		809	19
Ohio No. 938	19.4	18.5	279,300		147		855	14

TABLE No. 85.—*Summary of bacteriological observations—Monthly means at all stations by months, 1914 and 1915, with related data*—Continued

JUNE, 1914

Sampling stations	Monthly means							
	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from Pittsburgh (hours)	Turbidity (p. p. m.)	Bacteria per c. c. on—		B. Coli per c. c. (est.)
						Gelatin at 20° C.	Agar at 37° C.	
Allegheny No. 7	23. 0	3. 6	6, 530		20	8, 200	20, 700	44
Monongahela No. 12	24. 0	5. 8	2, 850		12	400	220	1
Ohio No. 3	24. 0	5. 8	9, 380	9. 1	38	9, 470	15, 200	220
Ohio No. 11	25. 0	5. 8	9, 380	34. 7	52	3, 160	10, 200	37
Ohio No. 19	24. 0	5. 8	9, 380	53. 1	50	1, 520	3, 380	23
Ohio No. 23	23. 4	5. 8	9, 380	60. 8	18	3, 900	6, 830	40
Beaver River	23. 4		850		26	3, 960	2, 830	190
Ohio No. 65	22. 7	6. 1	10, 300	106. 4	21		1, 580	14
Ohio No. 77	23. 7	6. 1	10, 300	131. 0	50		2, 280	42
Ohio No. 88	23. 7	6. 1	10, 300	146. 6	30		1, 540	29
Ohio No. 97	22. 6	6. 1	10, 300	160. 5	33		2, 680	118
Ohio No. 104	23. 3	6. 1	10, 300	173. 5	49		2, 530	92
Kanawha					25	100	183	1
Guyandotte					17	242	563	4
Big Sandy					20	425	722	4
Little Scioto	23. 8				52	605	1, 015	7
Ohio No. 349	25. 5	5. 8	17, 900	415. 4	30	334	438	9
Tygarts Creek	24. 4				51	344	678	6
Scioto River	24. 5	. 14	1, 000		91	1, 980	2, 850	171
Ohio No. 358	25. 3	5. 8	18, 900	421. 9	34	424	550	18
Ohio No. 461	26. 2	5. 3	19, 800	485. 3	12	220	190	1
Little Miami River			180		78	3, 650	5, 500	28
Licking River	27. 6	2. 0	1, 030		391	14, 100	8, 900	218
Millcreek					150	5, 450, 000	17,200,000	550, 000
Ohio No. 475	26. 2	5. 3	21, 000	501. 3	127	121, 000	237, 000	2, 930
Ohio No. 482	25. 8	5. 3	21, 000	512. 9	102	67, 500	91, 800	1, 220
Ohio No. 488	25. 6	5. 3	21, 000	518. 8	63	54, 000	50, 800	1, 330
Miami River	25. 6	2. 6	1, 240		74	1, 380	933	2
Ohio No. 492	25. 0	5. 3	22, 200	522. 0	47	41, 600	48, 900	530
Ohio No. 598	25. 3	6. 9	28, 800	667. 3	60	648	586	11
Ohio No. 611	25. 9	6. 9	28, 800	690. 1	69	15, 300	26, 300	255
Ohio No. 619	25. 9	6. 9	28, 800	696. 7	71	33, 800	52, 100	456
Ohio No. 904	26. 9	6. 0	46, 600	998. 1	62		646	3
Cumberland River	29. 4	7. 9	4, 540		50		213	2
Ohio No. 920	26. 9	6. 0	51, 100	1, 015. 5	46		690	3
Tennessee River	29. 6	2. 1	17, 100		82		130	1
Ohio No. 926	27. 6	6. 0	68, 200	1, 021. 9	43		530	1
Ohio No. 933	28. 0	6. 0	68, 200	1, 030. 1	37		534	5
Ohio No. 938	27. 7	6. 0	68, 200		33		390	2

JULY, 1914

Allegheny No. 7	24. 8	2. 1	3, 460		16	4, 560	9, 460	34
Monongahela No. 12	24. 9	6. 1	3, 660		8	55	100	2
Ohio No. 3	25. 1	6. 1	5, 380	16. 3	5	5, 300	10, 600	127
Ohio No. 9–11	24. 7	6. 1	5, 380	59. 8	4	640	3, 420	15
Ohio No. 19	24. 2	6. 1	5, 380	92. 4	7	1, 000	3, 100	35
Ohio No. 23	24. 5	6. 1	5, 380	106. 8	7	1, 040	5, 340	118
Beaver River	23. 8	. 68	460		11	5, 070	7, 850	502
Ohio No. 65	24. 6	7. 8	6, 630	178. 8	6	890	780	13
Ohio No. 77	25. 0	7. 8	6, 630	220. 4	7	1, 230	1, 260	28
Ohio No. 88	25. 0	7. 8	6, 630	244. 5	11	607	660	72
Ohio No. 97	24. 8	7. 8	6, 630	268. 6	8	4, 240	3, 800	161
Ohio No. 104	24. 8	7. 8	6, 630	290. 5	7	1, 640	2, 000	35
Muskingum River					49	210	428	1
Little Kanawha River					35		12, 000	55
Guyandotte River					20	220	354	10
Hocking River					28	100	370	1
Big Sandy River					10	45	43	. 1
Little Scioto River	24. 5				68	1, 450	4, 580	10
Ohio No. 349	26. 7	5. 4	16, 400	597. 2	100	872	1, 290	29
Tygarts Creek	24. 2				147	1, 510	1, 850	40
Scioto River	25. 6	—. 1	730		64	1, 940	3, 000	100
Ohio No. 358	26. 6	5. 4	17, 100	603. 8	79	810	1, 230	28
Ohio No. 461	27. 1	4. 9	18, 700	668. 1	22	320	400	7
Little Miami River			140		272	2, 440	3, 180	27

TABLE No. 85.—*Summary of bacteriological observations—Monthly means at all stations by months, 1914 and 1915, with related data*—Continued

JULY, 1914—Continued

Sampling stations	Monthly means							
	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from Pittsburgh (hours)	Turbidity (p. p. m.	Bacteria per c. c. on—		B. Coli per c. c. (est.)
						Gelatin at 20° C.	Agar at 37° C.	
Licking River	29.3	1.2	110	----------	63	4,770	4,320	280
Millcreek	----------	----------	----------	----------	----------	4,060,000	6,190,000	(1)
Ohio No. 475	27.3	4.9	19,000	686.3	25	101,000	147,000	6,190
Ohio No. 482	26.8	4.9	19,000	700.3	23	57,900	82,700	2,420
Ohio No. 488	27.2	4.9	19,000	706.5	26	19,700	29,900	1,770
Miami River	25.4	2.5	1,000	----------	233	3,080	3,030	153
Ohio No. 492	26.5	4.9	20,000	709.8	95	18,600	23,900	2,290
Ohio No. 598	27.0	6.0	23,100	883.9	7	292	203	1
Ohio No. 611	27.2	6.0	23,100	912.6	22	8,820	10,100	784
Ohio No. 619	27.2	6.0	23,100	920.4	14	31,400	34,400	1,230
Ohio No. 904	28.3	4.4	30,800	1,275.7	15	157	129	1
Cumberland River	28.9	8.7	8,000	----------	269	608	320	10
Ohio No. 920	28.9	4.4	38,800	1,296.3	87	208	200	2
Tennessee River	29.7	2.2	19,200	----------	90	116	164	3
Ohio No. 926	28.6	4.4	58,000	1,303.1	95	154	173	2
Ohio No. 933	29.0	4.4	58,000	1,311.7	72	155	153	2
Ohio No. 938	28.7	4.4	58,000	----------	125	----------	117	5

AUGUST, 1914

Allegheny No. 7	23.0	1.4	1,660	----------	15	7,420	22,900	784
Monongahela No. 12	24.8	6.0	2,050	----------	4	30	22	
Turtle Creek	----------	----------	----------	----------	22	1,140	748	11
Ohio No. 3	25.0	6.0	3,730	24.0	7	4,290	14,500	110
Ohio Nos. 9–11	24.6	6.0	3,730	89.6	4	495	2,000	34
Ohio No. 19	24.4	6.0	3,730	137.2	7	740	1,400	75
Ohio No. 23	24.0	6.0	3,730	158.2	7	1,020	2,100	28
Beaver River	23.0	.48	360	----------	17	6,440	11,200	550
Ohio No. 29	25.0	6.0	4,090	184.6	3	922	1,560	24
Ohio No. 65	24.2	8.2	4,650	275.6	4	370	835	19
Ohio No. 77	24.6	8.2	4,650	334.8	13	887	1,640	48
Ohio No. 88	24.4	8.2	4,650	370.9	13	670	720	48
Ohio No. 97	24.2	8.2	4,650	405.6	12	3,200	4,330	151
Ohio No. 104	23.9	8.2	4,650	437.8	26	2,500	2,740	212
Muskingum River	----------	----------	----------	----------	25	345	456	.8
Little Kanawha River	----------	----------	----------	----------	93	3,420	18,200	550
Guyandotte River	----------	----------	----------	----------	339	12,100	11,300	32
Hocking River	----------	----------	----------	----------	55	938	1,150	3
Kanawha River	----------	----------	----------	----------	103	1,230	328	1
Big Sandy River	----------	----------	----------	----------	57	211	499	28
Ohio No. 349	25.7	4.0	11,800	836.0	90	954	1,720	25
Scioto River	24.8	−.1	960	----------	174	4,120	11,400	182
Ohio No. 358	26.6	4.0	12,800	843.5	118	1,600	2,680	39
Ohio No. 461	26.4	3.7	13,900	919.0	145	1,280	1,350	24
Little Miami River	----------	6.4	550	----------	333	18,900	11,800	896
Licking River	27.2	1.8	740	----------	458	10,800	9,700	366
Millcreek	----------	----------	----------	----------	----------	4,580,000	11,400,000	86,200
Ohio No. 475	26.3	3.7	15,200	942.5	199	131,000	262,000	9,410
Ohio No. 482	25.8	3.7	15,200	959.0	173	21,000	41,100	1,120
Ohio No. 488	25.9	3.7	15,200	966.0	125	15,300	29,800	393
Miami River	23.7	2.5	1,270	----------	565	11,700	11,100	215
Ohio No. 492	25.0	3.7	16,600	969.5	130	17,600	39,600	807
Ohio No. 543	----------	3.7	16,700	1,048.4	----------	1,700	2,860	33
Kentucky River	----------	6.7	1,150	----------	----------	1,310	1,800	17
Ohio No. 598	26.0	5.1	18,300	1,177.6	24	2,140	1,250	102
Ohio No. 611	27.0	5.1	18,300	1,212.1	34	34.500	41,000	971
Ohio No. 619	27.1	5.1	18,300	1,221.2	28	63,600	77,000	1,190
Ohio No. 904	27.5	2.5	26,400	1,622.9	18	227	221	2
Cumberland River	28,0	8.5	6,880	----------	123	381	322	6
Ohio No. 920	27.9	2.5	33,300	1,642.9	41	226	225	3
Tennessee River	28.4	2.0	16,700	----------	60	199	174	1
Ohio No. 926	27.7	2.5	50,000	1,649.4	39	250	170	3
Ohio No. 933	27.9	2.5	50,000	1,658.0	39	160	170	6

[1] 2,117,000.

TABLE No. 85.—*Summary of bacteriological observations—Monthly means at all stations by months, 1914 and 1915, with related data*—Continued

SEPTEMBER, 1914

Sampling stations	Monthly means							
	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from Pittsburgh (hours)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C.	Bacteria per c. c. on— Agar at 37° C.	B. Coli per c. c. (est.)
Allegheny No. 7	19.0	1.6	2,250	—	18	10,200	16,000	105
Monongahela No. 12	21.0	6.0	960	—	5	20	18	.4
Turtle Creek	—	—	—	—	69	217	212	1.7
Ohio No. 3	21.0	6.0	3,370	25.3	14	35,400	41,100	726
Ohio No. 11	20.5	6.0	3,370	98.7	10	1,850	3,060	110
Ohio No. 19	20.5	6.0	3,370	153.8	13	1,200	1,100	134
Ohio No. 23	20.3	6.0	3,370	176.4	15	900	1,920	106
Beaver River	19.0	.53	390	—	17	9,190	9,860	775
Ohio No. 29	20.7	6.0	3,760	204.9	5	1,420	2,030	197
Ohio No. 65	19.8	8.0	4,500	323.7	33	614	384	42
Ohio No. 77	20.3	8.0	4,500	384.7	24	1,100	634	82
Ohio No. 88	20.4	8.0	4,500	420.8	25	530	388	43
Ohio No. 97	20.4	8.0	4,500	456.3	22	1,630	1,570	92
Ohio No. 104	20.3	8.0	4.500	488.5	23	1,520	1,000	49
Muskingum	—	—	—	—	69	335	294	4.3
Little Kanawha River	—	—	—	—	86	15,400	5,230	262
Guyandotte River	—	—	—	—	149	3,110	2,460	206
Hocking River	—	—	—	—	84	746	677	6
Kanawha River	—	—	—	—	108	103	177	34
Big Sandy River	—	—	—	—	93	727	500	30
Ohio No. 349	22.3	4.6	13,700	866.5	80	790	816	31
Scioto River	21.1	−.07	810	—	97	3,600	3,140	89
Ohio No. 358	22.1	4.6	14,500	873.5	89	1,100	1,330	25
Ohio No. 461	22.1	4.4	17,100	941.9	153	500	1,280	20
Little Miami River	—	5.9	160	—	44	2,280	2,620	181
Licking River	22.5	1.4	230	—	340	3,680	4,600	307
Millcreek	—	—	—	—	—	3,000,000	7,020,000	903,000
Ohio No. 475	22.6	4.4	17,500	962.1	94	95,700	170,000	5,190
Ohio No. 482	22.5	4.4	17,500	976.8	84	27,400	70,700	2,590
Ohio No. 488	22.3	4.4	17,500	983.3	86	21,000	50,800	2,550
Miami River	19.5	2.4	840	—	72	1,070	1,690	125
Ohio No. 492	22.0	4.4	18,300	986.8	92	16,400	40,600	2,390
Ohio No. 543	—	4.4	18,600	1,057.6	116	5,330	8,900	103
Kentucky River	—	6.9	1,530	—	132	860	2,630	3
Ohio No. 598	22.9	5.5	20,900	1,172.1	118	1,280	506	20
Ohio No. 611	22.9	5.5	20,900	1,202.7	133	30,700	30,300	709
Ohio No. 619	22.6	5.5	20,900	1,210.9	119	45,400	42,600	1,380
Ohio No. 904	23.3	4.6	37,300	1,576.9	150	677	811	22
Cumberland River	24.5	8.4	6,840	—	238	746	796	21
Ohio No. 920	23.7	4.6	44,200	1,594.9	186	593	684	24
Tennessee River	25.0	1.5	15,900	—	98	292	372	4
Ohio No. 926	24.0	4.6	60,100	1,601.5	173	579	656	21
Ohio No. 933	24.1	4.6	60,100	1,609.9	169	445	560	21
Ohio No. 938	24.0	4.6	60,100	—	189	603	868	29

OCTOBER 1, TO 15, INCLUSIVE, 1914

Allegheny No. 7	17.0	0.9	840	—	16	1,720	8,350	44
Monongahela No. 12	19.7	6.1	540	—	11	10	11	.2
Turtle Creek	—	—	—	—	121	381	145	2.4
Ohio No. 3	19.0	6.1	1,670	51	14	6,890	53,900	255
Ohio No. 5	18.5	6.1	1,670	—	10	1,230	32,900	70
Ohio No. 11	18.3	6.1	1,670	199	8	790	1,300	148
Ohio No. 19	18.8	6.1	1,670	304	18	1,220	1,450	70
Ohio No. 23	17.9	6.1	1,670	349	21	1,140	1,250	123
Beaver River	16.0	.25	240	—	15	7,720	6,520	640
Ohio No. 65	17.7	7.8	2,470	622	5	425	212	7
Ohio No. 77	18.2	7.8	2,470	742	5	614	470	14
Ohio No. 88	18.6	7.8	2,470	808	8	352	213	17
Ohio No. 97	18.2	7.8	2,470	871	8	3,420	2,460	113
Ohio No. 104	18.1	7.8	2,470	929	9	3,720	1,500	186
Muskingum River	—	—	—	—	25	144	185	1
Little Kanawha River	—	—	—	—	30	27,800	17,400	100
Guyandotte River	—	—	—	—	15	165	136	10
Hocking River	—	—	—	—	25	545	330	1
Kanawha River	—	—	—	—	7	85	147	.1
Big Sandy River	—	—	—	—	17	70	73	1
Ohio No. 349	20.2	1.9	4,440	1,639	21	522	836	32
Ohio No. 355	21.0	1.9	4,440	1,649	8	1,000	2,900	40
Scioto River	19.4	−.3	490	—	49	3,800	7,840	182

TABLE No. 85.—*Summary of bacteriological observations—Monthly means at all stations by months, 1914 and 1915, with related data*—Continued

OCTOBER 1 TO 15, INCLUSIVE, 1914—Continued

Sampling stations	Monthly means							
	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from Pittsburgh (hours)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C.	Bacteria per c. c. on— Agar at 37° C.	B. Coli per c. c. (est.)
Ohio No. 358	20.0	1.9	4,930	1,652	24	720	1,290	22
Ohio No. 461	20.1	1.2	7,210	1,755.7	24	849	1,370	11
Little Miami River		5.8	240		17	3,890	4,740	54
Licking River	19.3	1.7	960		178	8,220	8,630	334
Millcreek						2,370,000	4,040,000	61,400
Ohio No. 475	20.6	1.2	8,410	1,799	28	177,000	350,000	7,230
Ohio No. 482	18.5	1.2	8,410	1,828	25	15,700	27,400	455
Ohio No. 488	20.1	1.2	8,410	1,838	27	9,810	10,500	309
Miami River	18.3	2.1	650		54	1,320	1,490	10
Ohio No. 492	20.0	1.2	9,060	1,843	25	4,440	6,130	92
Ohio No. 543		1.2	9,190	1,973	7	530	544	2
Kentucky River		6.8	1,220		14	238	369	1
Ohio No. 598	19.6	2.9	[1] 10,400	2,270	6	215	318	4
Ohio No. 611	20.8	2.9	[1] 10,400	2,350	11	78,400	96,200	1,420
Ohio No. 619	20.8	2.9	[1] 10,400	2,360	10	44,700	71,000	1,240
Ohio No. 904	21.3	1.9	23,700	3,061	91	273	414	15
Cumberland River	21.5	7.5	3,320		285	828	618	20
Ohio No. 920	21.2	1.9	27,000	3,082	122	361	479	15
Ohio No. 926	21.4	1.9	39,300	3,090	120	829	894	22
Tennessee River	21.6	0.4	12,300		82	358	490	5
Ohio No. 933	21.4	1.9	39,300	3,100	106	644	740	36

[1] Estimated from discharge at station 543, plus discharge of Kentucky River. The discharge at Louisville as estimated from rating curve for Ohio River at Louisville is 7,510 second feet. that is, less than the discharge at Cincinnati.

OCTOBER, 1914

Sampling stations	Monthly means							
	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from station No. 475 (hours)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C.	Bacteria per c. c. on— Agar at 37° C.	B. Coli per c. c. (est.)
Ohio No 461	18.0	3.7	12,700		109	806	3,270	61
Little Miami River		6.7	622		89	4,180	3,800	112
Licking River	16.6	3.2	3,600		201	4,950	5,550	190
Mill Creek						1,660,000	2,940,000	36,900
Ohio No. 475	17.8	3.7	16,900		163	116,000	203,000	16,900
Ohio No. 482	17.9	3.7	16,900	16.8	100	38,400	48,900	1,500
Ohio No. 488	17.4	3.7	16,900	23.8	121	27,300	27,900	929
Miami River	16.1	2.5	1,240		63	2,650	1,820	22
Ohio No. 492	17.1	3.7	18,100	27.4	172	24,000	24,500	390
Ohio No. 543		3.7	18,400	106.0	98	4,950	3,800	36
Kentucky River		7.5	3,850		163	550	1,340	25
Ohio No. 598	18.0	5.5	22,400	234.0	73	1,040	700	11
Ohio No. 611	18.1	5.5	22,400	266.0	77	46,400	55,800	798
Ohio No. 619	18.0	5.5	22,400	274.4	81	54,800	57,900	755

NOVEMBER, 1914

Ohio No. 461	7.7	2.8	11,400		14	130	120	2
Little Miami River		5.9	148		14	2,590	1,140	43
Licking River	7.6	1.5	228		42	8,370	2,080	211
Mill Creek						929,000	732,000	31,000
Ohio No. 475	8.3	2.8	11,800	0	17	248,000	198,000	3,150
Ohio No. 482	8.3	2.8	11,800	19.9	16	102,000	67,700	1,480
Ohio No. 488	8.6	2.8	11,800	27.7	13	129,000	79,300	1,600
Miami River	7.3	2.2	782		23	6,120	1,570	14
Ohio No. 492	8.5	2.8	12,600	31.7	12	140,000	85,100	617
Ohio No. 543		2.8	12,800	123.3	16	3,900	3,150	43
Kentucky River		6.4	343		37	628	322	13
Ohio No. 598	10.0	3.9	12,300	282.3	11	206	124	4
Ohio No. 611	9.9	3.9	12,300	331.3	12	21,300	7,970	183
Ohio No. 619	10.2	3.9	12,300	343.8	13	58,800	26,900	344

TABLE No. 85.—*Summary of bacteriological observations—Monthly means at all stations by months, 1914 and 1915, with related data*—Continued

Sampling stations	Monthly means							
	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from station No. 475 (hours)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C.	Bacteria per c. c. on— Agar at 37° C.	B. Coli per c. c. (est.)
DECEMBER, 1914								
Ohio No. 461	4.7	15.2	81,100		283	4,560	3,630	107
Little Miami River		7.6	1,030		108	19,000	12,400	152
Licking River		5.2	8,730		275	16,700	13,950	152
Mill Creek						682,000	359,000	16,000
Ohio No. 475	4.7	15.2	88,200		337	52,700	25,700	923
Ohio No. 482	4.6	15.2	88,200	4.0	369	44,600	14,800	177
Ohio No. 488	4.9	15.2	88,200	6.9	323	84,900	45,400	162
Miami River	4.2	2.8	2,160		37	14,000	7,800	255
Ohio No. 492	4.6	15.2	90,400	8.7	301	80,200	37,400	296
Ohio No. 543		15.2	91,800	34.1	288	26,000	13,200	175
Kentucky River		8.6	7,320		337	15,500	4,590	55
Ohio No. 598	4.0	15.6	96,500	71.1	214	9,990	2,400	30
Ohio No. 611	3.7	15.6	96,500	79.7	294	13,300	3,350	56
Ohio No. 619	3.6	15.6	96,500	83.4	227	15,900	3,600	141
JANUARY, 1915								
Ohio No. 461	1.2	26.2	171,900		213	13,900	3,420	41
Little Miami River		8.8	2,610		345	73,700	15,900	62
Licking River		6.7	9,260		299	20,400	7,760	91
Mill Creek	1.8				53	234,000	54,400	3,000
Ohio No. 475	1.5	26.2	183,800		244	14,900	3,120	144
Ohio No. 482	1.5	26.2	183,800	2.8	258	14,700	2,640	114
Ohio No. 488	1.4	26.2	183,800	4.9	268	16,300	2,630	111
Miami River	1.0	4.3	3,890		196	53,200	13,000	297
Ohio No. 492	1.3	26.2	187,700	6.3	266	18,400	3,820	121
Ohio No. 543		26.2	190,500	24.5	206	17,200	2,280	182
Kentucky River		10.2	13,200		240	8,400	1,980	44
Ohio No. 598	1.6	29.1	221,600	44.5	267	13,800	2,780	36
Ohio No. 611	1.5	29.1	221,600	49.7	307	14,900	3,150	52
Ohio No. 619	1.6	29.1	221,600	52.3	306	13,900	2,690	43
FEBRUARY, 1915								
Ohio No. 461	2.7	35.2	223,000		151	10,000	1,350	51
Little Miami River	3.4	11.8	7,500		106	21,200	2,840	126
Licking River		6.8	10,640		124	14,100	2,140	19
Mill Creek	5.0				110	439,000	92,500	1,670
Ohio No. 475	3.3	35.2	245,100		143	13,800	1,820	186
Ohio No. 482	3.2	35.2	245,100	2.5	152	12,900	1,550	139
Ohio No. 488	3.2	35.2	245,100	4.4	138	12,400	1,250	70
Miami River	4.1	6.4	17,760		124	37,500	8,000	232
Ohio No. 492	3.2	35.2	262,900	5.7	143	16,000	2,040	227
Ohio No. 543		30.9	266,800	22.0	189	25,400	2,360	96
Kentucky River		9.8	12,300		210	17,700	2,330	141
Ohio No. 598	3.0	36.4	309,100	40.0	256	18,900	2,240	47
Ohio No. 611	3.3	36.4	309,100	44.7	269	18,200	2,290	41
Ohio No. 619	3.3	36.4	309,100	47.1	261	18,500	2,460	34
MARCH, 1915								
Ohio No. 461	3.9	17.9	79,400		80	6,640	560	19
Little Miami River	4.2	7.2	633		31	11,100	800	34
Licking River		4.1	4,210		148	6,710	1,040	27
Mill Creek	6.2				129	380,000	144,000	21,100
Ohio No. 475	4.5	17.9	84,200		90	12,400	2,480	363
Ohio No. 482	4.5	17.9	84,200	3.9	87	8,580	1,160	65
Ohio No. 488	4.5	17.9	84,200	6.8	93	9,520	1,470	70
Miami River	5.2	4.1	3,030		39	11,500	2,370	33
Ohio No. 492	4.4	17.9	87,200	8.6	82	9,110	2,010	84
Ohio No. 543		16.7	88,500	33.7	104	8,960	1,370	85
Kentucky River		8.6	7,020		94	20,000	3,240	140
Ohio No. 598	4.7	16.4	98,800	69.9	86	5,040	543	16
Ohio No. 611	4.9	16.4	98,800	78.4	100	5,540	617	23
Ohio No. 619	4.9	16.4	98,800	82.0	100	6,140	597	24

Table No. 85.—*Summary of bacteriological observations—Monthly means at all stations by months, 1914 and 1915, with related data*—Continued

APRIL, 1915

Sampling stations	Monthly means							
	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from station No. 475 (hours)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C.	Agar at 37° C.	B. Coli per c. c. (est.)
Ohio No. 461	12.3	11.8	40,000	----------	24	944	160	5
Little Miami River	14.4	6.4	280	----------	47	3,510	1,120	98
Licking River	----------	2.5	1,330	----------	161	1,650	417	15
Mill Creek	16.7	----------	----------	----------	137	8,440,000	9,260,000	57,100
Ohio No. 475	12.4	11.8	41,600	----------	26	68,400	64,100	1,090
Ohio No. 482	12.3	11.8	41,600	6.2	27	59,100	53,300	868
Ohio No. 488	12.0	11.8	41,600	10.3	26	87,300	78,400	946
Miami River	14.4	3.7	1,900	----------	41	6,380	2,300	13
Ohio No. 492	11.9	11.8	43,500	12.7	28	76,700	67,700	660
Ohio No. 543	----------	12.0	44,200	50.6	16	11,100	10,300	239
Kentucky River	----------	7.3	2,740	----------	28	900	343	1
Ohio No. 598	12.8	10.0	48,300	112.5	12	935	220	3
Ohio No. 611	12.8	10.0	48,300	128.8	15	1,220	350	27
Ohio No. 619	12.8	10.0	48,300	133.8	19	8,590	3,140	63

MAY, 1915

Ohio No. 461	19.0	14.7	50,900	----------	45	2,930	1,530	72
Little Miami River	18.2	6.6	607	----------	724	39,600	17,500	115
Licking River	----------	4.2	4,500	----------	1,760	22,300	14,900	290
Mill Creek	19.0	----------	----------	----------	187	5,170,000	5,970,000	142,000
Ohio No. 475	18.8	14.7	56,000	----------	324	57,400	54,700	1,730
Ohio No. 482	18.7	14.7	56,000	5.2	276	49,600	54,100	1,860
Ohio No. 488	19.0	14.7	56,000	8.8	310	51,200	58,400	1,230
Miami River	17.8	3.9	2,840	----------	129	5,730	3,240	28
Ohio No. 492	18.8	14.7	58,800	11.0	328	43,800	47,500	1,680
Ohio No. 543	----------	13.2	59,700	43.2	236	28,100	32,000	770
Kentucky River	----------	7.5	3,760	----------	88	3,240	3,590	27
Ohio No. 598	19.2	11.5	63,800	95.7	171	4,790	3,450	47

JUNE, 1915

Ohio No. 461	22.2	16.7	69,500	----------	281	4,760	2,100	49
Little Miami River	21.9	7.8	1,310	----------	311	12,200	3,800	63
Licking River	----------	4.0	3,960	----------	1,450	16,700	14,200	293
Mill Creek	21.5	----------	----------	----------	503	1,430,000	1,720,000	145,000
Ohio No. 475	22.3	16.7	74,800	----------	413	23,700	27,800	1,320
Ohio No. 482	22.8	16.7	74,800	4.3	427	25,300	24,900	1,440
Ohio No. 488	22.3	16.7	74,800	7.4	430	33,100	35,900	1,200
Miami River	22.2	4.4	4,230	----------	446	10,300	11,000	203
Ohio No. 492	22.3	16.7	79,000	9.3	387	34,100	34,400	1,580
Ohio No. 543	----------	15.5	80,200	36.3	374	16,800	15,000	296
Kentucky River	----------	8.1	5,420	----------	477	35,000	29,700	139
Ohio No. 598	22.9	15.8	94,100	77.5	246	3,540	3,220	56

JULY, 1915

Ohio No. 461	24.9	17.3	66,300	----------	369	6,850	3,840	127
Little Miami River	----------	7.9	1,540	----------	657	21,300	15,900	114
Licking River	----------	5.4	7,370	----------	982	24,100	16,700	618
Mill Creek	23.5	----------	----------	----------	587	3,350,000	7,530,000	219,000
Ohio No. 475	24.9	17.3	75,200	----------	642	45,900	57,300	3,300
Ohio No. 482	25.0	17.3	75,200	4.2	605	33,800	37,700	1,760
Ohio No. 488	25.0	17.3	75,200	7.3	632	40,000	42,200	1,470
Miami River	23.6	5.6	11,300	----------	992	28,000	17,200	410
Ohio No. 492	24.9	17.3	86,500	9.2	751	43,800	39,800	1,400
Ohio No. 543	----------	16.4	87,800	35.9	410	100,000	58,900	496
Kentucky River	----------	9.3	9,450	----------	968	86,700	50,900	168
Ohio No. 598	25.6	16.8	102,500	75.7	314	4,510	4,500	102

TABLE No. 85.—*Summary of bacteriological observations—Monthly means at all stations by months, 1914 and 1915, with related data*—Continued

Sampling stations	Monthly means							
	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from station No. 475 (hours)	Turbidity (p. p. m.)	Bacteria per c. c. on—		B. Coli per c. c. (est.)
						Gelatin at 20° C.	Agar at 37° C.	
AUGUST, 1915								
Ohio No. 461	24.0	13.9	50,200		172	4,780	3,150	121
Little Miami River		8.5	2,060		576	33,100	44,200	232
Licking River		3.2	2,580		660	21,500	14,000	252
Mill Creek	21.0				211	2,720,000	4,610,000	106,000
Ohio No. 475	24.1	13.9	54,800		273	43,200	51,900	1,800
Ohio No. 482	24.0	13.9	54,800	5.1	280	35,300	35,400	1,100
Ohio No. 488	23.9	13.9	54,800	8.6	261	64,800	54,500	1,180
Miami River	21.9	4.7	5,440		444	54,400	28,700	791
Ohio No. 492	23.9	13.9	60,200	10.8	332	73,500	64,200	1,570
Ohio No. 543		13.3	61,100	42.2	257	78,300	47,700	344
Kentucky River		7.8	4,280		359	55,400	44,700	139
Ohio No. 598	24.3	12.4	66,400	93.2	157	3,730	2,810	56
SEPTEMBER, 1915								
Ohio No. 461	22.2	13.8	48,200		160	3,790	2,300	66
Little Miami River		8.3	2,600		193	20,100	15,600	262
Licking River		2.3	1,260		206	14,600	12,900	139
Mill Creek	19.9				161	2,150,000	3,740,000	42,000
Ohio No. 475	22.5	13.8	52,100		174	44,900	60,300	1,380
Ohio No. 482	22.6	13.8	52,100	5.7	177	50,100	56,700	1,850
Ohio No. 488	22.6	13.8	52,100	9.5	163	48,200	54,900	1,330
Miami River	20.8	4.8	6,400		145	21,400	14,200	306
Ohio No. 492	22.3	13.8	58,400	11.8	185	42,200	44,600	1,120
Ohio No. 543		12.9	59,300	47.0	201	96,400	82,900	958
Kentucky River		7.1	2,260		254	56,000	50,000	425
Ohio No. 598	22.6	11.7	61,200	104.9	114	2 900	2,880	71
OCTOBER, 1915								
Ohio No. 461	16.0	16.1	66,200		157	4,400	2,000	65
Little Miami River		7.6	1,330		136	18,000	10,700	189
Licking River		3.3	2,860		124	6,900	4,000	117
Mill Creek	15.4				158	3,590,000	2,960,000	82,300
Ohio No. 475	16.6	16.1	70,400		169	42,300	39,200	567
Ohio No. 482	16.5	16.1	70,400	4.6	174	76,400	70,900	1,320
Ohio No. 488	16.6	16.1	70,400	8.0	164	90,400	69,600	1,860
Miami River	15.3	4.4	4,630		118	23,800	8,370	212
Ohio No. 492	16.5	16.1	75,000	10.0	175	61,000	43,400	1,230
Ohio No. 543		14.7	76,100	38.4	153	21,300	13,900	159
Kentucky River		8.1	5,300		197	13,700	9,760	42
Ohio No. 598	16.5	14.3	85,100	83.4	146	4,600	3,070	65
NOVEMBER, 1915								
Ohio No. 461	10.0	15.9	53,200		89	6,630	2,080	41
Little Miami River		7.1	910		71	31,700	16,500	42
Licking River		3.8	4,430		135	15,100	9,340	280
Mill Creek	10.0				120	2,680,000	2,270,000	36,600
Ohio No. 475	10.4	15.9	58,600		96	97,100	72,700	819
Ohio No. 482	10.2	15.9	58,600	5.4	92	121,000	88,700	1,090
Ohio No. 488	10.2	15.9	58,600	9.0	93	83,200	61,100	815
Miami River	8.8	4.1	3,410		44	23,900	15,700	213
Ohio No. 492	10.3	15.9	62,000	11.2	79	72,700	53,500	905
Ohio No. 543			62,900	44.2	115	39,300	27,000	338
Kentucky River		8.3	7,060		173	9,280	5,720	63
Ohio No. 598	10.5	12.6	72,500	98.3	118	7,120	3,360	44

TABLE NO. 85.—*Summary of bacteriological observations—Monthly means at all stations by months, 1914 and 1915, with related data*—Continued

DECEMBER, 1915

Sampling stations	Monthly means: Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from station No. 475 (hours)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C.	Agar at 37° C.	B. Coli per c. c. (est.)
Ohio No. 461	2.9	24.2	125,000		182	18,900	2,420	28
Little Miami River		9.2	7,180		70	30,900	10,500	121
Licking River		9.4	16,840		255	17,500	5,400	124
Mill Creek	4.6				231	388,000	193,000	7,370
Ohio No. 475	3.1	24.2	149,000		211	27,200	5,930	270
Ohio No. 482	3.0	24.2	149,000	3.1	210	25,500	4,220	111
Ohio No. 488	2.9	24.2	149,000	5.9	198	22,800	4,180	151
Miami River	2.3	4.8	6,580		153	40,000	9,500	118
Ohio No. 492	2.8	24.2	155,600	7.4	198	25,000	4,870	239
Ohio No. 543			157,900	27.7	178	21,300	4,030	156
Kentucky River		14.9	54,000		319	24,400	6,050	149
Ohio No. 598	3.3	25.4	201,000	51.7	293	60,100	4,870	56

JANUARY, 1916

Sampling stations	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from station No. 475 (hours)	Turbidity (p. p. m.)	Gelatin at 20° C.	Agar at 37° C.	B. Coli per c. c. (est.)
Ohio No. 461	3.2	37.8	273,500		235	29,400	2,940	25
Little Miami River		12.5	11,900		328	50,300	7,600	51
Licking River		9.9	18,600		477	32,900	4,800	85
Ohio No. 475	3.7	37.8	304,000		277	25,200	3,800	117
Ohio No. 482	3.5	37.8	304,000	2.04	288	25,800	3,900	112
Ohio No. 488	3.5	37.8	304,000	3.86	284	27,000	3,620	125
Miami River	3.7	7.7	28,240		432	85,800	16,400	233
Ohio No. 492	3.5	37.8	332,240	5.13	315	34,500	4,800	146
Ohio No. 543		37.8	337,200	20.10	364	38,400	6,500	70
Kentucky River		12.2	24,200		599	43,200	6,800	30
Ohio No. 598	4.2	44.2	401,000	36.46	364	35,500	4,800	69

FEBRUARY, 1916

Sampling stations	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from station No. 475 (hours)	Turbidity (p. p. m.)	Gelatin at 20° C.	Agar at 37° C.	B. Coli per c. c. (est.)
Ohio No. 461	3.3	30.3	204,000		207	20,500	1,850	27
Little Miami River		9.3	3,410		114	18,800	4,000	32
Licking River		8.1	12,540		300	22,600	3,600	43
Ohio No. 475	3.8	30.3	220,000		234	14,300	3,300	125
Ohio No. 482	2.7	30.3	220,000	2.7	238	13,800	2,900	123
Ohio No. 488	2.8	30.3	220,000	4.6	240	14,000	2,850	92
Miami River	2.8	5.7	13,480		167	28,000	11,300	323
Ohio No. 492	3.5	30.3	233,480	6.0	257	15,600	3,300	78
Ohio No. 543		30.3	237,000	22.7	249	15,900	3,600	141
Kentucky River		10.0	12,120		212	15,100	2,700	32
Ohio No. 598	3.6	35.2	287,000	41.3	332	29,200	4,200	107

MARCH, 1916

Sampling stations	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from station No. 475 (hours)	Turbidity (p. p. m.)	Gelatin at 20° C.	Agar at 37° C.	B. Coli per c. c. (est.)
Ohio No. 461	3.7	28.4	189,000		329	33,800	2,560	19
Little Miami River		10.5	6,280		495	52,200	15,400	44
Licking River		7.7	9,890		448	25,100	5,200	49
Ohio No. 475	4.5	28.4	205,000		397	28,200	4,000	55
Ohio No. 482	4.3	28.4	205,000	2.7	391	27,100	3,700	132
Ohio No. 488	4.3	28.4	205,000	4.8	429	27,400	3,600	74
Miami River	5.5	6.0	13,620		337	51,500	13,300	260
Ohio No. 492	4.1	28.4	218,620	6.1	411	29,400	4,400	91
Ohio No. 543		28.4	221,900	23.5	276	23,300	3,400	102
Kentucky River		9.9	11,010		232	12,100	3,800	157
Ohio No. 598	4.8	30.6	233,000	42.7	451	32,300	4,000	78

APRIL, 1916

Sampling stations	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from station No. 475 (hours)	Turbidity (p. p. m.)	Gelatin at 20° C.	Agar at 37° C.	B. Coli per c. c. (est.)
Ohio No. 461	9.8	28.5	198,000		107	9,080	704	19
Little Miami River		9.4	4,080		64	5,300	9,600	42
Licking River		4.3	5,374		72	5,000	1,400	38
Ohio No. 475	9.9	28.5	207,000		105	11,100	4,600	118
Ohio No. 482	9.9	28.5	207,000	2.7	107	11,500	5,200	78
Ohio No. 488	9.9	28.5	207,000	4.8	107	11,600	5,280	102
Miami River	11.1	5.1	7,430		206	31,700	6,000	115
Ohio No. 492	9.8	28.5	214,430	6.1	118	12,900	5,800	160
Ohio No. 543		28.5	217,600	23.4	92	21,200	4,800	38
Kentucky River		8.6	7,014		95	16,800	8,900	18
Ohio No. 598	10.9	31.7	258,000	42.6	151	9,900	2,000	29

TABLE No. 85.—*Summary of bacteriological observations—Monthly means at all stations by months, 1914 and 1915, with related data*—Continued

MAY, 1916

Sampling stations	Monthly means							
	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from station No. 475 (hours)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C.	Bacteria per c. c. on— Agar at 37° C.	B. Coli per c. c. (est.)
Ohio No. 461	17. 2	16. 9	92, 700	----------	123	3, 010	660	12
Little Miami River	----------	7. 9	1, 840	----------	114	7, 700	3, 100	30
Licking River	----------	2. 8	2, 226	----------	121	5, 400	2, 200	33
Ohio No. 475	17. 7	16. 9	96, 800	----------	146	26, 000	27, 500	601
Ohio No. 482	17. 5	16. 9	96, 800	3. 6	137	29, 200	30, 400	586
Ohio No. 488	17. 5	16. 9	96, 800	6. 4	139	43, 800	37, 200	546
Miami River	17. 5	5. 1	8, 064	----------	205	19, 300	9, 800	183
Ohio No. 492	17. 5	16. 9	104, 864	8. 1	163	41, 600	37, 600	387
Ohio No. 543	----------	16. 9	106, 400	31. 8	104	19, 100	18, 400	233
Kentucky River	----------	7. 3	2, 842	----------	25	25, 300	16, 900	18
Ohio No. 598	18. 6	17. 7	114, 000	64. 0	130	6, 300	2, 800	61

JUNE, 1916

Sampling stations	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from station No. 475 (hours)	Turbidity (p. p. m.)	Gelatin at 20° C.	Agar at 37° C.	B. Coli per c. c. (est.)
Ohio No. 461	20. 9	18. 4	101, 000	----------	306	5, 850	2, 190	61
Little Miami River	----------	8. 4	1, 900	----------	242	22, 600	13, 800	205
Licking River	----------	5. 2	6, 233	----------	485	13, 000	7, 500	183
Ohio No. 475	21. 0	18. 4	109, 000	----------	339	19, 800	27, 200	617
Ohio No. 482	21. 0	18. 4	109, 000	3. 4	357	18, 800	20, 100	326
Ohio No. 488	20. 9	18. 4	109, 000	5. 9	326	30, 300	28, 200	340
Miami River	20. 5	5. 2	8, 592	----------	323	19, 100	14, 200	128
Ohio No. 492	20. 8	18. 4	117, 592	7. 6	321	35, 500	32, 600	688
Ohio No. 543	----------	18. 4	119, 400	29. 9	340	27, 310	19, 400	280
Kentucky River	----------	7. 7	3, 674	----------	274	45, 100	33, 000	49
Ohio No. 598	21. 4	18. 9	126, 000	58. 7	357	12, 200	4, 800	128

JULY, 1916

Gage heights designated (*) indicate that dam was raised during a part, or whole of the month, forming pool above]

Sampling stations	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from station No. 475 (hours)	Turbidity (p. p. m.)	Gelatin at 20° C.	Agar at 37° C.	B. Coli per c. c. (est.)
Ohio No. 461	26. 3	*10. 1	46, 100	----------	183	914	949	11
Little Miami River	----------	6. 6	337	----------	163	5, 200	3, 200	113
Licking River	----------	1. 9	797	----------	95	4, 344	2, 400	51
Ohio No. 475	26. 3	*10. 1	47, 200	----------	222	64, 700	86, 700	1, 037
Ohio No. 482	26. 2	*10. 1	47, 200	5. 9	221	48, 600	63, 600	742
Ohio No. 488	26. 1	*10. 1	47, 200	9. 8	227	43, 400	60, 000	767
Miami River	25. 6	3. 5	1, 450	----------	97	1, 900	2, 200	20
Ohio No. 492	26. 0	*10. 1	48, 850	12. 1	209	36, 300	55, 900	783
Ohio No. 543	----------	*10. 1	49, 380	48. 1	103	18, 800	31, 100	164
Kentucky River	----------	6. 9	1, 651	----------	151	131, 300	117, 700	352
Ohio No. 598	27. 7	11. 1	61, 400	107. 2	88	3, 600	4, 100	36

AUGUST, 1916

[Gage heights designated (*) indicate that dam was raised during a part, or whole of the month, forming pool above]

Sampling stations	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from station No. 475 (hours)	Turbidity (p. p. m.)	Gelatin at 20° C.	Agar at 37° C.	B. Coli per c. c. (est.)
Ohio No. 461	26. 1	9. 8	43, 100	----------	506	3, 440	3, 090	34
Little Miami River	----------	6. 4	283	----------	295	24, 700	16, 600	342
Licking River	----------	3. 0	2, 194	----------	895	12, 400	10, 800	287
Ohio No. 475	26. 1	*9. 8	45, 600	----------	503	47, 400	74, 200	1, 313
Ohio No. 482	26. 0	*9. 8	45, 600	6. 0	453	61, 200	97, 350	2, 097
Ohio No. 488	25. 9	*9. 8	45, 600	10. 0	363	57, 200	83, 500	1, 880
Miami River	24. 5	3. 4	1, 016	----------	438	16, 400	11, 100	167
Ohio No. 492	25. 7	*9. 8	46, 616	12. 4	361	49, 100	72, 800	2, 061
Ohio No. 543	----------	*9. 8	47, 320	49. 4	232	15, 900	20, 400	276
Kentucky River	----------	7. 5	4, 122	----------	305	26, 900	13, 300	36
Ohio No. 598	28. 7	11. 0	58, 000	109. 8	216	2, 700	5, 100	113

TABLE No. 85.—*Summary of bacteriological observations—Monthly means at all stations by months, 1914 and 1915, with related data*—Continued

SEPTEMBER, 1916

[Gage heights designated (*) indicate that dam was raised during a part, or whole of the month, forming pool above]

Sampling stations	Monthly means							
	Temperature, ° C.	River stage (feet)	Discharge (second-feet)	Time of flow from station No. 475 (hours)	Turbidity (p. p. m.)	Bacteria per c. c. on— Gelatin at 20° C.	Agar at 37° C.	B. Coli per c. c. (est.)
Ohio No. 461	22.2	4.8	17,400	----------	38	858	661	3
Little Miami River	----------	6.1	298	----------	195	25,000	16,900	213
Licking River	----------	1.8	994	----------	481	16,200	9,600	220
Ohio No. 475	22.2	*4.8	18,700	----------	65	170,100	151,900	2,300
Ohio No. 482	22.0	*4.8	18,700	13.5	47	114,000	142,200	3,100
Ohio No. 488	23.7	*4.8	18,700	19.8	43	46,100	49,000	1,470
Miami River	19.5	3.4	1,102	----------	71	11,600	3,800	15
Ohio No. 492	21.3	*4.8	19,802	23.0	48	46,500	39,600	900
Ohio No. 543	----------	*4.8	20,100	89.7	29	18,200	11,200	35
Kentucky River	----------	6.6	959	----------	124	44,000	45,500	16
Ohio No. 598	24.6	6.5	25,900	196.5	24	700	800	10

OCTOBER, 1916

[Gage heights designated (*) indicate that dam was raised during a part, or whole of the month, forming pool above]

Ohio No. 461	14.9	*5.6	23,400	----------	51	999	1,160	13
Little Miami River	----------	5.8	120	----------	32	6,700	5,800	122
Licking River	----------	1.7	704	----------	243	24,100	23,700	135
Ohio No. 475	15.6	*5.6	24,200	----------	78	194,400	216,100	5,689
Ohio No. 482	15.5	*5.6	24,200	10.7	79	96,000	98,100	4,797
Ohio No. 488	15.2	*5.6	24,200	16.5	73	57,600	54,100	1,750
Miami River	13.6	3.2	666	----------	12	1,600	1,900	38
Ohio No. 492	14.9	*5.6	24,868	19.6	69	51,900	49,000	1,375
Ohio No. 543	----------	*5.6	25,230	69.6	32	10,200	8,100	189
Kentucky River	----------	6.7	1,613	----------	43	28,600	17,000	6
Ohio No. 598	17.9	6.8	27,800	165.4	33	833	800	6

NOVEMBER, 1916

[Gage heights designated (*) indicate that dam was raised during a part, or whole of the month, forming pool above]

Ohio No. 461	9.0	*4.7	17,800	----------	19	783	477	5
Little Miami River	----------	5.7	102	----------	24	16,500	5,810	219
Licking River	----------	1.6	340	----------	99	2,800	2,000	99
Ohio No. 475	9.3	*4.7	18,200	----------	18	144,800	102,200	4,710
Ohio No. 482	9.0	*4.7	18,200	13.9	16	178,250	118,700	1,595
Ohio No. 488	8.9	*4.7	18,200	20.2	16	190,000	118,000	3,050
Miami River	7.6	3.2	562	----------	11	26,600	2,900	21
Ohio No. 492	8.7	*4.7	18,762	23.5	16	204,500	115,500	2,836
Ohio No. 543	----------	*4.7	19,040	91.2	18	45,300	18,100	925
Kentucky River	----------	6.4	383	----------	27	10,100	3,400	28
Ohio No. 598	12.6	5.7	21,400	199.2	18	2,500	800	37

DECEMBER, 1916

[Gage heights designated (*) indicate that dam was raised during a part, or whole of the month, forming pool above.]

Ohio No. 461	4.3	*12.1	56,300	----------	118	13,500	1,100	60
Little Miami River	----------	7.3	1,690	----------	193	78,000	16,700	190
Licking River	----------	4.8	5,644	----------	428	26,600	9,500	122
Ohio No. 475	4.0	*12.1	63,600	----------	153	34,600	12,300	317
Ohio No. 482	4.1	*12.1	63,600	4.9	158	25,800	8,640	139
Ohio No. 488	3.9	*12.1	63,600	8.3	174	34,700	9,680	230
Miami River	4.2	3.4	1,425	----------	49	35,600	5,200	34
Ohio No. 492	3.9	*12.1	65,025	10.4	160	33,500	10,800	293
Ohio No. 543	----------	*12.1	66,000	40.9	127	22,200	6,200	57
Kentucky River	----------	7.5	5,440	----------	357	60,200	6,700	6
Ohio No. 598	7.7	14.1	71,000	89.9	235	25,400	4,500	72

RELATIONS BETWEEN GELATIN COUNTS, AGAR COUNTS AND B. COLI DETERMINATIONS

The routine bacteriological examination of all samples included gelatin counts, agar counts and quantitative tests for *B. coli*, because it was thought that each of these determinations might give useful information supplementing that afforded by the other two.

The gelatin count at 20° C. is the standard measure of a heterogeneous group of bacteria developing under conditions of substratum and temperature selected with a view to favoring the growth of organisms which find their optimum environment in nature outside of the animal body, within the usual range of out-of-door temperatures.

The standard agar count at 37° C. is the measure of another heterogeneous group, developing under conditions which presumably are more favorable to the multiplication of bacteria having their natural habitat and optimum environment in the bodies of warm-blooded animals and adapted to body temperatures.

The two groups of bacteria represented by these two standard counts overlap to an undetermined extent; and it is not improbable that a large majority of the bacterial species appearing on 20° gelatin plates from sewage or polluted surface water also appear on 37° agar plates from the same source, and vice versa. It is generally believed, however, that even though the species included in the two counts may be much the same, their distributions differ in that the gelatin count of surface water includes a relatively greater proportion of bacteria originating in soil wash, and the agar count a greater proportion of those originating in or in close association with the bodies of animals. It is to be expected, therefore, that the ratio of gelatin to agar count will be higher in ordinary topsoil and in water polluted chiefly with soil wash than in sewage and in water highly and freshly polluted with sewage.

The relative importance and sanitary significance of gelatin and agar counts, respectively, in the examination of water and sewage doubtless varies according to circumstances. The agar count is presumably the more accurate index of the extent of pollution with the most objectionable and most harmful classes of wastes. The gelatin count has, however, been in general use for a longer period of years, especially in the examination of drinking water and in the operation of water purification plants; and experience in water bacteriology is based largely on the gelatin counts, so that to many persons of wide experience it is more significant than the less familiar 37° agar count.

At the time when this study was begun, a number of those entitled to authoritative opinion held the view that all bacteria conforming to the standard tests for *B. coli* as applied in this work were of fecal

origin. In the light of more recent work, separating this group into two subgroups of colon (fecal) and aerogenes (nonfecal) types, this view is no longer tenable unless the tests applied include type differentiation, identifying the organism in question as belonging to the "true *B. coli*" (fecal) subgroup. Nevertheless, even without such differentiation the *B. coli* group as identified in this study, without type differentiation, is still a relatively homogeneous group, at least far less heterogeneous than the groups included in the gelatin and agar plate counts, and a far more specific index of fecal contamination. It is, however, subject to the disadvantage that the method of quantitative estimation applied, by fermentation tests, is less precise than the method of plate counts.

RATIO OF 20° GELATIN COUNTS TO 37° AGAR COUNTS

A cursory comparison of the gelatin and agar counts summarized in Tables 84 and 85 will serve to show that at practically all stations the ratio of these two counts varies from month to month, and that, as a general rule, the gelatin count greatly exceeds the agar count during the winter months, while during the summer and autumn months the agar count more nearly equals or even exceeds the gelatin count. The variations in this respect are illustrated in Table No. 86, showing the ratios of gelatin counts to agar counts at nine sampling stations on the Ohio River and its tributaries, for each month during which observations were made.

TABLE NO. 86.—*Ratios of gelatin counts to agar counts at nine sampling stations, by months*

Sampling stations	Ratio of gelatin count to agar count (=1.0)											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Allegheny A-7	------	------	12.4	5.5	0.9	0.4	0.5	0.3	0.6	0.2	------	------
Monongahela M-12	------	------	11.4	11.1	2.4	1.8	.6	1.3	1.1	.9	------	------
Ohio station 3	------	------	7.8	------	2.2	.6	.5	.3	.9	.1	------	------
Beaver River	------	------	------	4.0	1.8	1.4	.6	.6	.9	1.2	------	------
Ohio station 65	------	------	------	------	------	------	1.1	.4	1.6	2.0	------	------
Ohio station 461:												
1914	45.2	14.4	22.2	6.7	6.3	1.2	.8	1.0	.4	.2	1.1	1.3
1915	4.1	7.4	11.8	5.9	1.9	2.3	1.8	1.5	1.6	2.2	3.2	7.8
1916	10.0	11.1	13.2	12.9	4.6	2.7	1.0	1.1	1.3	.9	1.6	12.3
Ohio station 475:												
1914	8.6	11.4	6.5	2.7	.6	.5	.7	.5	.6	.6	1.2	2.0
1915	4.8	7.6	5.0	1.1	1.0	.8	.8	.8	.7	1.1	1.3	4.6
1916	6.6	4.3	7.1	2.4	1.0	.7	.7	.6	1.1	.9	1.4	2.8
Ohio station 598:												
1914	------	4.6	6.0	1.2	1.1	1.1	1.4	1.7	2.5	.7	1.7	4.1
1915	5.0	8.4	9.3	4.2	1.4	1.1	1.0	1.3	1.0	1.5	2.1	6.2
1916	7.4	6.9	8.0	4.9	2.2	2.5	.9	.5	.9	1.0	3.0	5.6
Mill Creek:												
1914	------	------	------	------	------	.3	.7	.4	.4	.6	1.3	1.9
1915	4.3	4.8	2.6	.9	.9	.8	.4	.6	.6	1.2	1.2	2.0
1916	7.0	3.0	2.9	1.4	.7	.5	.5	.4	.6	.9	1.2	1.5

In any given month the gelatin-agar ratios at the several sampling stations shown in this table vary rather widely, but within limits which change from month to month. Thus, in successive periods in the year 1914, the maximum and minimum ratios observed at these stations are as follows:

Period, 1914	Maximum ratio	Minimum ratio
January–March	[1] 45.2	2.6
April	12.9	.9
May	6.3	.6
June–November	3.2	.1
December	12.3	1.3

[1] This ratio is exceptionally high, and the next highest ratio observed, 22.2 (at station 461, in March, 1916), probably more nearly represents the usual upper limit at the stations included in the table.

There is, then, a well-defined tendency toward a higher gelatin-agar ratio in the winter and early spring months, and a lower ratio in the summer and autumn.

At four of the sampling stations included in the table, namely, stations 461, 475, 598, and Mill Creek, sample collections were continued through 1914, 1915, and 1916, so that data are available to show the successive changes in gelatin-agar ratios during three years; and it may be noted that the change from high ratios in winter to low ratios in summer recurs regularly each year at all these stations. Averaging the ratios at each station for corresponding months during the three years, an average ratio has been calculated for each month of the seasonal cycle at each station, as shown in Table No. 87, following:

TABLE No. 87.—*Mean ratios of gelatin counts to agar counts at four sampling stations, by months, for the years 1914, 1915, and 1916, combined*

Sampling stations	Ratio of gelatin count to agar count (=1.0)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
Ohio station No. 461	[1] 19.8	11.0	15.7	8.5	4.3	2.1	1.2	1.2	1.1	1.1	2.0	7.1	6.26
Ohio station No. 475	6.7	7.8	6.2	2.1	.87	.67	.73	.63	.80	.87	1.3	3.1	2.65
Ohio station No. 598	6.2	6.6	7.8	3.4	1.6	1.6	1.1	1.2	1.5	1.1	2.3	5.3	3.31
Mill Creek	[2] 5.7	[2] 3.9	[2] 2.8	[2] 1.1	[2] .80	.53	.53	.47	.53	.90	1.2	1.8	1.69

[1] Disregarding the very unusual ratio (45.2) observed in January, 1914, the average for the month would be 7.15, which is probably a more representative figure.
[2] Data available for only two years, 1915 and 1916; sampling begun in June, 1914.

These four stations are selected for purposes of illustration because they represent very wide variations with respect to intensity, character, and sources of bacterial pollution, which may be briefly described as follows:

Station 461.—Bacterial flora partly from urban sewage discharged into the river system from 150 to 600 miles above; partly from surface drainage of a large rural watershed.

Mill Creek.—Bacterial flora almost exclusively that of fairly fresh urban sewage.

Station 475.—Bacterial flora that of station 461, plus an admixture of sewage from the Cincinnati metropolitan district, which constitutes from 25 per cent to more than 95 per cent of the bacteria present.

Station 598.—Bacterial flora practically the same in origin as that of station 475, but greatly reduced in number by natural agencies of purification, which presumably have also effected some change in the relative numbers of different species.

The seasonal variations in gelatin-agar ratios at these four stations are similar in kind, but with distinct and fairly consistent quantitative differences. Thus, with few exceptions, the ratio in corresponding months is highest at station 461, next highest at station 598, next at station 475, and lowest in Mill Creek. These differences are consistent with the usual view that bacteria of the 20° gelatin group are relatively more numerous in soil wash and those of the 37° agar group more numerous in sewage. Thus, the proportion of the 20° gelatin group is highest at station 461, where presumably the bacteria from soil wash form a larger proportion of the total than at any of the other stations; it is least in Mill Creek, where the greatest proportion of the bacteria are of sewage origin; and at station 475 it is, as expected, intermediate between these extremes. Comparing stations 475 and 598, it might be expected that the natural agencies bringing about a bacterial reduction between these stations would affect the bacteria of the 37° agar group relatively more than those of the 20° gelatin group, resulting in a higher gelatin-agar ratio at 598 than at 475, since the gelatin group presumably comprises a larger proportion of species which find a favorable environment in water. The higher gelatin-agar ratio expected at station 598 upon this hypothesis is actually noted there.

RATIO OF 37° AGAR COUNT TO B. COLI

The varying ratios of monthly mean agar counts to *B. coli* at the nine sampling stations already cited in the study of gelatin-agar ratios, are shown in Table No. 88. At each station the ratio varies from month to month, but so irregularly that there is little or no evidence of a regular seasonal cycle such as is characteristic of the gelatin-agar ratio. The average ratios for each month, based on three years' results at stations 461, 598, 475, and Mill Creek, as shown in Table No. 89, are likewise irregular, with no well-marked, progressive seasonal change. Comparing the several stations, there is again no regular or consistent tendency to higher ratios at one station than at another.

TABLE NO. 88.—*Ratios of agar counts to B. coli at nine sampling stations, by months*

Sampling stations	Year	Ratio of agar count to B. coli (=1.0)											
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Allegheny A-7	1914			80.0	33.3	416.0	471.0	278.0	294.0	152.0	190.0		
Monongahela M-12	1914			15.0	16.7	13.7	220.0	50.0	31.4	45.0	55.0		
Ohio No. 3	1914	5.1	4.5	5.6		12.4	69.0	83.5	132.0	56.6	211.0		
Beaver River	1914				16.7	14.7	14.9	15.6	20.4	12.7	10.2		
Ohio station 65	1914					13.3	113.0	60.0	44.0	9.1	30.3		
Ohio station 461	1914	25.9	27.2	42.7	26.6	20.5	190.0	57.1	52.5	64.0	124.0	60.0	33.9
	1915	83.5	26.5	29.5	32.0	21.2	43.0	30.2	26.0	34.8	30.8	50.7	86.4
	1916	117.8	68.6	134.8	37.1	55.0	35.9	86.4	90.8	220.3	89.2	95.2	18.3
Ohio station 475	1914	23.5	10.9	25.6	32.2	149.0	80.9	23.8	27.8	32.8	48.3	62.9	27.8
	1915	21.7	9.8	6.8	58.8	31.6	21.1	17.4	28.9	43.7	69.2	88.7	22.0
	1916	32.5	26.5	72.7	39.1	45.6	44.1	83.4	56.7	66.0	38.0	21.7	38.8
Ohio station 598	1914	88.1	57.7	86.8	29.8	28.7	53.3	203.0	12.2	25.3	79.5	31.0	80.0
	1915	77.2	47.7	34.0	73.3	73.4	57.4	44.1	50.2	40.5	47.4	76.4	87.0
	1916	69.8	39.2	51.3	69.1	45.8	37.5	114.1	45.2	80.0	133.3	21.6	62.8
Mill Creek	1914						31.4	2.9	132.0	7.8	79.7	23.6	22.4
	1915	18.1	55.4	6.8	162.0	42.0	11.7	34.4	43.5	89.2	35.9	63.2	26.2
	1916	41.4	19.5	47.7	66.0	43.4	151.0	94.4	56.4	42.0	45.0	34.5	81.4

TABLE NO. 89.—*Mean ratios of agar counts to B. coli at four sampling stations, by months, for the years 1914, 1915, and 1916, combined*

Sampling stations	Ratios of agar counts to B. coli (=1.0)												Average	December to March	April to November
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.			
Ohio station 461	75.7	40.8	69.0	31.9	32.2	89.6	57.9	56.4	106.4	81.3	68.6	46.2	63.0	57.9	65.5
Ohio station 475	25.9	15.7	35.0	43.4	75.4	48.7	41.5	37.8	47.5	51.8	57.8	29.5	42.5	26.5	50.5
Ohio station 598	78.3	48.2	57.4	57.4	49.3	49.4	120.4	35.9	48.6	86.7	43.0	76.6	62.6	65.1	61.3
Mill Creek	[1] 29.8	[1] 37.4	[1] 27.2	[1] 114.0	[1] 42.7	[1] 64.7	43.9	77.3	46.3	53.5	40.4	43.3	51.7	34.4	60.4

[1] Averages calculated from results in 1915 and 1916: Sampling not begun until June, 1914.

RATIO OF GELATIN COUNTS TO B. COLI

The ratios of gelatin counts to *B. coli*, as shown in Tables Nos. 90 and 91, show (except at station No. 3) a well defined and fairly regular seasonal variation similar to that shown in the gelatin-agar ratio, the ratios tending to be higher in winter than in summer. Similarly, as between the four stations included in Table No. 91, the ratio tends generally to be highest at station 461, next highest at station 598, and lowest at station 475 or Mill Creek.

TABLE No. 90.—*Ratios of gelatin counts to B. coli at nine sampling stations, by months*

Sampling stations	Ratio of gelatin count to B. coli (=1.0)											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
llegheny, A-7	------	------	961	182	390	186	134	95	97	39	------	------
Ionongahela, M-12	------	------	171	186	27	400	28	43	50	50	------	------
hio, 3	------	------	44	37	27	43	42	39	49	27	------	------
eaver River	------	------	------	67	27	21	10	12	12	12	------	------
hio, station 65	------	------	------	------	------	------	68	19	15	61	------	------
hio, station 461:												
1914	1, 170	390	945	178	129	220	46	50	25	77	65	43
1915	339	196	350	189	41	97	54	40	57	68	162	676
1916	1, 176	760	1, 780	478	251	96	83	101	286	77	157	225
hio station, 475:												
1914	203	126	167	86	85	41	16	14	18	24	79	57
1915	103	74	34	63	33	18	14	24	32	75	119	101
1916	215	114	512	94	43	32	62	36	74	34	31	109
hio, station 598:												
1914	------	268	522	35	31	50	292	21	64	54	52	333
1915	386	402	315	312	102	63	44	67	41	71	162	538
1916	514	273	413	340	103	95	100	24	70	139	68	352
Iill Creek:												
1914	------	------	------	------	------	10	2	53	3	45	30	43
1915	78	263	18	148	36	10	15	26	51	44	73	53
1916	291	59	137	117	31	76	47	24	25	40	43	125

TABLE No. 91.—*Mean ratios of gelatin counts to B. coli at four sampling stations, by months, for the years 1914, 1915, and 1916, combined*

Sampling stations	Ratios of gelatin counts to B. coli (=1.0)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
hio, station No. 461	895	449	1, 025	282	140	138	61	64	[1] 123	74	128	315	308
hio, station No. 475	174	105	238	81	54	30	31	25	41	44	76	89	82
hio, station No. 598	[2] 450	314	417	229	79	72	[3] 145	37	58	88	94	408	199
Iill Creek	[2] 184	[2] 161	[2] 78	[2] 132	[2] 34	32	21	34	26	43	49	74	72

[1] Average ratio for two years, 1914 and 1915, is 41.
[2] No data for 1914; average of 1915 and 1916 ratios.
[3] Average ratio for two years, 1915 and 1916, is 72.

SUMMARY

Although the foregoing discussion has referred to results at only a few sampling stations, the facts noted are of much more general application, as is readily seen from review of results at other sampling stations on the Ohio River and its tributaries, as shown in the basic tables. From these data it is evident that there are no constant quantitative relations between the three broad groups of bacteria distinguished by the 20° gelatin count, the 37° agar count and the standard tests for *B. coli*, respectively. The gelatin-agar and gelatin-*B. coli* ratios are lower in sewage and in waters highly polluted with fresh sewage than in water more remotely polluted with sewage and carrying relatively more soil-wash pollution, tending to confirm the usual view that the gelatin count group is more characteristic of soil wash, while the agar count and *B. coli* groups are more characteristic of sewage.

The ratios of gelatin count to agar count and of gelatin count to *B. coli* undergo regular and wide seasonal variations, such that during the winter and spring months there is a great relative increase in bacteria of the gelatin count group as compared to both the agar count and *B. coli* groups. The agar-*B. coli* ratio shows no such regular tendency to seasonal variation nor to consistent variation in waters differing in intensity and freshness of sewage pollution.

The increased gelatin-agar and gelatin-*B. coli* ratios are characteristic of the seasons when the run-off of the Ohio River is ordinarily greatest, and it might seem, therefore, that the changes in ratio are accounted for by the increased proportion of soil wash and the decreased proportion of sewage carried by the river in such seasons. However, the same changes in ratio are noted in Mill Creek, where, even in periods of greatest run-off, the total numbers of bacteria from soil wash must be small in proportion to those from sewage, and ordinary sanitary sewage shows similar changes. Also, it is noted that the changes in ratio in the Ohio River correspond more closely to season than to hydrographic conditions, the latter being markedly different in corresponding months of 1914, 1915, and 1916. Apparently, therefore, the changes in relative numbers of these groups are biological phenomena related rather intimately to temperature.

POLLUTION OF THE OHIO RIVER IN ZONES FROM WHICH WATER SUPPLIES ARE TAKEN

The Ohio River is the natural and most readily available source of water supply for all the cities situated upon its banks, excepting the few small cities which have ground-water supplies available in sufficient abundance for their needs. Including Pittsburgh, which takes its water supply from the Allegheny River about 7 miles above its confluence with the Monongahela, the Ohio River furnishes municipal water supplies to 31 cities, having, in 1915, an aggregate population of 1,778,000, of which 1,216,000 is comprised within the cities of Pittsburgh, Cincinnati, and Louisville.

The contamination of these water supplies with pathogenic organisms, causing typhoid fever and other water-borne infections, is the most serious danger arising from the sewage pollution of the stream; and adequate protection against this danger will, in all probability, be the paramount consideration in whatever measures may be taken in the future for controlling the pollution. The first question to be answered as the basis for future sanitary control of the stream is, therefore, What constitutes adequate protection for the water supplies taken from it?

There is no question as to the fitness of the waters of the Ohio River for use without purification. A general knowledge of the

drainage area and of the sanitary history of the cities which have in the past taken their water supplies from the Ohio River without purification are sufficient, without the evidence of bacteriological examinations, to establish beyond question that throughout the length of the river its waters are so polluted as to be wholly unfit to be used for drinking without efficient artificial purification, and that, even if the direct sewage pollution were reduced to an absolute minimum by the utmost possible purification of all urban sewage, artificial purification of water supplies would still be necessary for removal of turbidity and for protection against dangerous contamination from rural drainage.

A purification plant of the highest efficiency reasonably attainable may, therefore, be considered an indispensable element in the protection of any water supply taken from the river. Another necessary element of protection is, of course, that each community should locate its intake above its own sewer outlets and other drainage—a precaution commonly disregarded twenty years ago but now universally observed by Ohio River cities. The third measure of artificial protection to be considered is purification of the sewage from upstream communities. In view of the expense and other difficulties incident to the enforcement of sewage purification, it is generally conceded that this measure of protection should be resorted to only as actually required to supplement the protection afforded by dilution, by the processes of natural purification in rivers, and by artificial purification of water supplies. Therefore, the pollution in zones from which water supplies must be drawn should be considered from the standpoint of the fitness of the water to be used, after such purification as can be achieved by modern methods at a reasonable cost and without too greatly narrowing the margin of safety which every water-purification plant should have.

Sampling stations corresponding very closely to the intakes for municipal waterworks were located at station A–7 on the Allegheny River, opposite the intake of the Pittsburgh waterworks; and on the Ohio, at stations No. 65, above Steubenville, Ohio; No. 88, above Wheeling; No. 348, above Portsmouth, Ohio; No. 461, above Cincinnati; and No. 598, above Louisville. The results of bacteriological examinations made at these stations are given in the corresponding sections of Table No. 84; but for convenience of comparison the observations made during 1914 are reassembled here in Table No. 92, showing, for all six stations, the monthly means of gelatin counts, agar counts, and *B. coli* determinations, respectively.

TABLE No. 92.—*Monthly mean results of bacteriological examinations at sampling stations corresponding approximately to intakes for municipal water supplies, 1914*

Months	Bacteria per cubic centimeter on gelatin at 20° C.					
	Station A-7	Station 65	Station 88	Station 348	Station 461	Station 598
January					19,900	
February				12,500	19,500	22,800
March	7,690			8,200	18,900	16,700
April	2,180			3,400	4,620	3,830
May	5,850			1,240	2,450	3,050
June	8,200			334	220	648
July	4,500	890	607	872	320	292
August	7,420	370	670	954	1,200	2,140
September	10,200	614	530	790	500	1,280
October	1,720	425	352	522	850	215
November					130	206
December					4,560	9,990
January-March	7,690			10,350	19,400	19,750
April-May	4,015			2,320	3,535	3,440
June-October	6,410	575	540	694	618	915

Months	Bacteria per cubic centimeter on agar at 37° C.					
	Station A-7	Station 65	Station 88	Station 348	Station 461	Station 598
January				816	440	2,730
February				993	1,360	4,900
March	640			630	854	2,780
April	400			1,060	690	3,250
May	6,250	519	447	904	390	2,780
June	20,700	1,580	1,540	440	190	586
July	9,460	780	660	1,290	400	203
August	22,900	835	720	1,720	1,260	1,250
September	16,000	384	388	816	1,280	506
October	8,350	212	213	836	1,370	318
November					120	124
December					3,630	2,400
January-March	640			813	885	3,470
April-May	3,325	519	447	982	540	3,015
June-October	15,480	758	704	1,020	900	573

Months	B. Coli per cubic centimeter					
	Station A-7	Station 65	Station 88	Station 348	Station 461	Station 598
January				21	17	31
February				51	50	85
March	8			19	20	32
April	12			33	26	109
May	15	39	28	25	19	97
June	44	14	29	9	1	11
July	34	13	72	29	7	1
August	78	19	48	25	24	102
September	105	42	43	31	20	20
October	44	7	17	32	11	4
November					2	4
December					107	30
January-March	8			30	29	49
April-May	14	39	28	29	23	103
June-October	61	19	44	25	13	28

The observations at Cincinnati (station 461) and Louisville (station 598), extending over a full year, are sufficient to indicate quite reliably the range of pollution encountered there, especially so since they may be compared with further observations at these stations throughout 1915 and 1916 (see Table No. 84); and the results at Portsmouth (station 348), though extending over only 10 months, cover a sufficient portion of a seasonal cycle to be fairly representative. The results at Pittsburgh (A–7), Steubenville (65), and Wheeling (88), on the other hand, can not be considered as really representative of usual conditions in those zones, since they cover only a part of the seasonal cycle, and refer chiefly to a period (June–October, 1914) when the Ohio was at an exceptionally low stage and when bacteriological conditions were probably unusual.

From these data, the pollution, as measured by *B. coli*, gelatin and agar counts, was highest at station A–7 (Pittsburgh), and least at station 598 (Louisville), during the low-water summer period, June to October, while during the period of high water and low temperature, from January to March, this order was reversed, the pollution being least at station A–7 and greatest at station 598.

Stations 65 and 88, located at distances below Pittsburgh which are indicated in miles by their respective numbers, show remarkably little pollution, considering that the sewage of the entire Pittsburgh metropolitan district is discharged at such a short distance above them, and that several smaller cities discharge their sewage into the intervening stretch of the river. It should be remembered, however, that, excepting the month of May, the period of observation at these stations was one of exceptionally low river stages, such that the interval of flow from Pittsburgh to station 65 ranged from 100 to more than 600 hours, with an additional interval of 40 to 180 hours between stations 65 and 88. Therefore, these sampling stations, though rather close to Pittsburgh in respect of distance, were, during this period, quite remote from that city in respect of time. The observations upon the upper Ohio are not sufficient to indicate with any certainty what the degree of pollution in these zones of the river may be during the higher river stages which are normal to the winter and spring months. At such times, when the series of dams (see pp. 16, 18) which retard the low-water flow are removed, the velocity of the river in this part of its course is quite high, and the time interval between Pittsburgh and station 65 is reduced to 21.5 hours at a river stage of 17.5 feet on the lower gage of Dam No. 10, which is not unusual.

The river zones represented by sampling stations 348 (Portsmouth), 461 (Cincinnati), and 598 (Louisville), are similar to each other in that they are all rather remote from any considerable sources of

direct sewage pollution. Thus, the sewered population within 100 miles above Portsmouth is about 56,100 and within a like distance above Cincinnati is 9,000, while above Louisville the nearest source of sewage pollution of any consequence is Cincinnati, 133 miles upstream. As might be expected from this general similarity of location the differences between these three sections with respect to pollution were not very wide nor were they very consistent during 1914.

At stations 461 (Cincinnati) and 598 (Louisville), observations were continued through the years 1914, 1915, and 1916, and these more ample data permit a more significant comparison between these two stations, which is of some interest in view of the fact that the river at Louisville is exposed to pollution from all the sources above Cincinnati, and, in addition, to whatever pollution is added in the sewage of the Cincinnati metropolitan district. Comparing the observations at these two stations as given in full in Table No. 84, it is seen that the bacterial pollution is higher sometimes at one and sometimes at the other of these stations, but that the excess is somewhat more frequently noted at station 598. For more convenient comparison the monthly mean results at both stations for the entire three years are rearranged in Table No. 93, in which the data (monthly mean) at station 461 are arranged in descending order of magnitude, with the results at station 598 in the corresponding month set opposite.[1]

[1] The averages for gelatin counts, agar counts, and *B. coli* are independent of each other, so that figures for these three determinations in the same horizontal row do not necessarily refer to the same month; but under each determination the data given for station 598 refer to the same months as at station 461.

TABLE No. 93.—*Comparison of monthly mean bacterial counts at stations 461 (Cincinnati) and 598 (Louisville), during three years, 1914, 1915, and 1916*

[Data arranged in order of magnitude of counts at station 461, with counts for corresponding months at station 598]

Bacteria per cubic centimeter (monthly means)					
Gelatin		Agar		B. coli	
461	598	461	598	461	598
33, 800	32, 200	3, 840	4, 500	127	102
29, 400	35, 500	3, 630	2, 400	121	56
20, 500	29, 200	3, 420	2, 780	107	30
19, 500	22, 800	3, 270	700	72	47
18, 900	16, 700	3, 150	2, 810	66	71
18, 900	30, 100	3, 090	5, 100	65	65
13, 900	13, 800	2, 940	4, 800	61	11
13, 500	25, 400	2, 560	4, 000	61	128
10, 000	18, 900	2, 420	4, 870	60	72
[a] 19, 820	[a] 24, 950	[a] 3, 150	[a] 3, 550	[a] 82	[a] 65
9, 080	9, 900	2, 300	2, 880	51	47
6, 850	4, 510	2, 190	4, 800	50	85
6, 640	5, 040	2, 110	3, 220	49	56
6, 630	7, 120	2, 080	3, 360	41	36
5, 850	12, 200	2, 000	3, 070	41	44
4, 780	3, 730	1, 850	4, 200	34	113
4, 760	3, 540	1, 530	3, 450	28	56
4, 620	3, 830	1, 360	4, 900	27	107
4, 560	9, 990	1, 350	2, 240	26	109
[a] 5, 970	[a] 6, 650	[a] 1, 860	[a] 3, 570	[a] 39	[a] 73
4, 400	4, 600	1, 280	506	25	69
3, 790	2, 900	1, 260	1, 250	24	102
3, 440	2, 700	1, 160	800	20	32
3, 010	6, 300	1, 100	4, 500	20	20
2, 930	4, 790	949	4, 100	19	97
2, 450	3, 050	854	2, 780	19	16
1, 200	2, 140	704	2, 000	19	78
999	833	690	3, 250	19	29
944	935	661	800	17	31
[a] 2, 570	[a] 3, 140	[a] 962	[a] 2, 220	[a] 20	[a] 53
914	3, 600	660	2, 800	13	6
858	700	560	543	12	61
806	1, 040	477	800	11	36
783	2, 500	440	2, 730	7	1
500	1, 280	400	203	5	3
320	292	390	2, 780	5	37
220	648	190	586	3	10
130	206	160	220	2	4
----------	----------	120	124	1	11
[a] 566	[a] 1, 280	[a] 377	[a] 1, 200	[a] 7	[a] 19

From this table it is readily seen:

(1) That there is a very definite correlation between counts at the two stations, indicating that they are in general similarly affected by seasonal and stream-flow conditions.

(2) That the higher counts occur more frequently at Louisville than at Cincinnati.

(3) That in each range of counts at station 461, as represented by the four quartiles the average count is higher at Louisville than at Cincinnati, with a single exception in the case of the *B. coli* determination.[2]

[a] Quartile averages.

[2] The higher average for *B. coli* at station 461 in the first quartile is accounted for by the fact that an exceptionally high monthly mean *B. coli* index is usually due largely to an excessive result on one or two days, and is therefore to be regarded as accidental; hence, there is little likelihood that exceptionally high results will coincide at two stations. When the data are arrayed in the order of results at Louisville, the mean for the first quartile then becomes higher there.

It is a fair inference from these data that the excess of pollution at station 598 over that at station 461 is due to the effect of the wastes from the Cincinnati metropolitan district and perhaps, in some slight degree, to pollution carried in the Miami River, for the other factors intervening between the two stations (time and dilution) would tend generally toward a reduction in bacterial content.

Whether or not the water in the river zones represented in Table No. 92 is fit for use with such purification as is practicable at reasonable cost is a question which can not be answered satisfactorily from the evidence of bacteriological examinations alone. At all six sampling stations the number of *B. coli* in most months was more than 5 per cubic centimeter, thus exceeding the limits of permissible pollution tentatively adopted by the International Joint Commission[3] for application in control of the pollution of international boundary waters; and the gelatin and agar counts are also rather high at Pittsburgh, Cincinnati, and Louisville, although there are no definite standards by which to judge them. On the whole, the pollution, as judged by the rather elastic and indefinite bacteriological standards ordinarily applied is at least in the upper range of what would be considered permissible in raw water, but not high enough to definitely condemn the waters as unfit for use with careful and consistent purification.

Bacteriological quality of filtered water supplies.—Better evidence than can be derived from the above results alone is afforded by the quality of the filtered water supplies of Pittsburgh, Cincinnati, and Louisville, as actually delivered through their filtration plants, since all three of these cities have filtration plants of modern design which are operated under the most careful skilled supervision and which may therefore be taken as representing in their performance, approximately the best that can be expected of filtration plants. The type of filter used at Pittsburgh, a slow sand filter with special preliminary treatment, is quite unusual in the Ohio Basin, and due to certain peculiarities in the physical and chemical characteristics of the water which it treats it is hardly comparable to any other purification plant existing upon the Ohio River. The mechanical filtration plants at Cincinnati and Louisville are, however, quite typical of the plants in use elsewhere on the Ohio and generally considered to be best adapted to the purification of water having the physical and chemical characteristics of Ohio river water. The results achieved in these plants may, therefore, be considered possible of achievement by other plants treating Ohio River water of about the same degree of pollution.

Table No. 94 following, summarizes the results of bacteriological examinations of samples of filtered water taken daily from taps in

[3] International Joint Commission, Pollution of Boundary Waters, Report of the Consulting Sanitary Engineer upon Remedial Measures, G. P. O., Washington, 1916, p. 13.

ur laboratories in Pittsburgh, Cincinnati, and Louisville, respectively. The results at the three cities are generally similar. The water supplies do not conform to the high standards which the best of present-day purification plants attempt to meet; but at the same time, even considering the dangerous pollution of their sources, they could hardly be pronounced dangerous on the bacteriological evidence of occasional slight pollution. They belong, in fact, in the class which, on epidemiological as well as bacteriological evidence, can neither be convicted of demonstrable danger nor fully acquitted of suspicion.

TABLE No. 94.—*Monthly mean results of daily bacteriological examinations of samples from municipal (filtered) water supplies of Pittsburgh, Cincinnati, and Louisville*

Month	Bacteria per cubic centimeter						B. coli per 100 cubic centimeters		
	Gelatin, 20° C.			Agar, 37° C.					
	Pittsburgh	Cincinnati	Louisville	Pittsburgh	Cincinnati	Louisville	Pittsburgh	Cincinnati	Louisville
1914									
January	--------	228	--------	42	10	8	0	0.4	2
February	--------	238	119	3	4	17	0	2	20
March	6	22	66	5	4	18	1	0.4	20
April	22	45	14	8	4	4	0	2	4
May	12	50	8	7	4	5	2	4	0.5
June	10	104	14	9	70	27	2	12	7
July	28	55	19	17	46	12	19	17	5
August	12	25	17	36	32	13	17	30	1.0
September	9	29	29	12	10	20	40	10	3
October	[1] 9	11	32	[1] 10	8	37	[1] 3	9	6
November	--------	6	11	--------	3	14	--------	2	16
December	--------	69	74	--------	20	21	--------	97	5
1915									
January	--------	22	114	--------	3	16	--------	6	3
February	--------	190	69	--------	1	6	--------	2	1
March	--------	98	4	--------	6	3	--------	0	0.4
April	--------	9	5	--------	1	3	--------	0	4
May	--------	59	13	--------	44	19	--------	490	5
June	--------	11	19	--------	6	29	--------	8	49
July	--------	49	10	--------	20	106	--------	18	10
August	--------	31	19	--------	21	35	--------	13	4
September	--------	21	15	--------	17	16	--------	13	2
October	--------	12	23	--------	7	12	--------	19	1
November	--------	13	49	--------	4	16	--------	7	1
December	--------	4	68	--------	2	12	--------	0	1
1916 [2]									
January	--------	97	46	--------	5	8	--------	0.8	1.3
February	--------	47	99	--------	3	20	--------	0.8	7.8
March	--------	47	3	--------	2	3	--------	0.0	0.2
April	--------	37	9	--------	3	3	--------	2.0	0.8
May	--------	44	20	--------	5	15	--------	1.5	5.2
June	--------	62	57	--------	20	36	--------	53.0	20.0

[1] Mean for period Oct. 1 to 15.
[2] Counts for 1916 refer to samples of final (chlorinated) effluent taken at the filtration plants at Cincinnati and Louisville. All counts for 1914 and 1915 refer to samples from taps in the city distribution system.

Evidence from typhoid fever mortality rates.—Fortunately, in this instance, the mortality statistics of the three cities furnish evidence which is reasonably conclusive. In Table No. 95 are shown the annual death rates from typhoid fever in Pittsburgh, Cincinnati, and Louisville, respectively, and in the entire group of registration

cities in the United States, for the 20 years from 1901 to 1920, inclusive. Records for two additional cities on the Ohio River, Portsmouth, and East Liverpool, Ohio, which continued to use untreated water from the river until 1914 and 1918, respectively, are added for comparison.

TABLE No. 95.—*Annual death rates from typhoid fever in Pittsburgh, Cincinnati, Louisville, Portsmouth, and East Liverpool, and in all registration cities of the United States, 1901–1920* [1]

Year	Annual death rates from typhoid fever per 100,000 population					
	Cities in United States registration area	Pittsburgh [2]	Cincinnati	Louisville	Portsmouth	East Liverpool
1901	33.7	107.7	54.7	46.3	59.5	----------
1902	37.2	133.5	61.5	61.2	68.2	----------
1903	37.8	126.2	42.2	61.1	86.6	----------
1904	34.7	134.9	79.2	63.4	74.3	----------
1905	29.6	114.8	40.4	51.2	77.1	----------
1906	33.5	143.6	70.2	70.6	56.3	----------
1907	32.0	125.4	45.4	71.4	86.8	----------
1908	25.0	48.9	18.2	46.7	71.2	----------
1909	21.2	24.6	13.3	*45.0*	47.8	64.6
1910	23.7	27.8	8.8	31.7	59.3	83.1
1911	20.1	25.7	11.4	23.9	74.0	96.1
1912	16.2	13.2	7.8	22.0	68.5	66.1
1913	16.5	19.7	6.9	23.5	122.7	106.9
1914	14.2	15.2	6.4	26.5	*122.2*	82.3
1915	11.6	10.5	7.6	14.3	28.4	72.0
1916	11.2	9.1	3.3	13.8	34.8	62.0
1917	10.9	12.2	4.0	16.3	21.0	65.4
1918	9.6	10.7	4.8	16.3	[3] 27.0	[3] *79.2*
1919	6.4	6.5	3.0	10.7	25.0	32.9
1920	5.9	5.6	3.2	5.5	12.0	46.6

[1] At Pittsburgh delivery of filtered water to central sections of city was begun in December, 1907, and gradually extended until the whole city was supplied in 1914. From 1911 to 1914 the unfiltered water supplied to a part of the city was chlorinated. The filtration plant at Cincinnati was put into operation in November, 1907; at Louisville in August, 1909; at Portsmouth in November, 1914; and at East Liverpool in May, 1918.

[2] Death rates for years 1901 to 1907 include the city of Allegheny, which was annexed to Pittsburgh in 1908.

[3] Rate based on census population of 1920

A detailed epidemiological analysis of the relation between the water supplies of these cities and the prevalence of typhoid fever in their inhabitants would require much more evidence than that of bare mortality figures, but these serve at least to bring out certain salient facts, namely:

(1) During the period preceding the installation of their filtration plants Pittsburgh, Cincinnati, and Louisville all suffered excessively high typhoid fever mortality rates in comparison with the contemporary experience of other American cities. There is abundant evidence in the more detailed records of morbidity and mortality which are available for these years to establish beyond reasonable doubt that the use of the highly polluted river water was the predominant factor in the causation of typhoid fever in these cities. It is, however, unnecessary to adduce this evidence here, since the conclusion to which it leads is already generally accepted.

(2) Following the installation of filtration plants, the mortality from typhoid fever was immediately and sharply reduced to approximately the level then prevailing in American cities generally—somewhat lower in the case of Cincinnati, and rather higher in the case of Louisville. As it is generally conceded that this reduction, at least to the level attained in the years immediately following the installation of filter plants, was largely if not wholly due to improvement in the water supplies, resulting from their purification, it is again unnecessary to cite more detailed evidence supporting this conclusion.

(3) Subsequent to the primary reduction in typhoid death rates immediately following the installation of purification plants in Pittsburgh, Cincinnati, and Louisville, there has been a further progressive decline in all three cities. Undoubtedly, during these years, from about 1910 to 1920, there has also been considerable and progressive improvement in the quality of their water supplies, due to the supplementary use of chlorination and to other refinements in operation of the plants. Just what part this progressive improvement in the water supplies during the last decade may have had in the coincident progressive decline in mortality from typhoid fever is, however, a difficult, perhaps unanswerable question, for the decline has not been local, but quite general throughout the United States, not only in cities but in rural areas as well. Thus, as regards the years 1914 to 1915, referred to in the bacteriological records given in Table 94, it is impossible to say that none of the typhoid fever occurring in these cities was due to infection conveyed in their public water supplies; but it is equally impossible to specifically incriminate the water supplies, since other possible sources of infection would seem competent to account for the observed prevalence.

(4) Finally, it may be said of these cities that ever since their water purification plants have been put into full operation, their mortality rates have compared favorably with those of American cities generally.[4] This implies that the sum total of protection afforded against typhoid fever in these three cities, including protection of their water supplies as one item in the total, has been up to the contemporary standards of American cities in general—well above these standards in the case of Cincinnati. As to the proportionate part, if any, which infection conveyed in their water supplies may have played in causation of the residual prevalence of typhoid fever in recent years, this is certainly not determinable from mortality rates alone, and it is probable that the most searching epidemiological investigations which could be made would not lead to any conclusions much more specific than those stated above.

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[4] Although the mortality rates at Louisville have generally been above the average for all the registration cities of the United States, they have not been higher than those of cities as far or farther south.

The experience of Pittsburgh, Cincinnati, and Louisville may be taken, then, as demonstrating that up to this time it has been found possible to purify the Ohio River water as available at their intakes sufficiently to afford at least a very efficient if not absolutely perfect protection against water-borne typhoid fever; and while this result has not been achieved without difficulties in the operation of the plants, it has been achieved at a reasonable cost.

Similar questions concerning the fitness of water from the Ohio River zones represented by stations 65 (Steubenville), 88 (Wheeling), and 348 (Portsmouth) can not be answered as yet with equal confidence. The water of the Ohio River at Portsmouth (station 348) is quite similar in respect of its bacterial content,[5] physical and chemical characteristics, to the water treated at Cincinnati and Louisville, so it is a fair inference that the efficiency of purification achieved at the latter two cities is possible of achievement at Portsmouth, though perhaps at greater proportionate expense. At stations 65 (Steubenville) and 88 (Wheeling) our observations, as previously noted, do not cover a sufficiently long period to indicate with certainty the range of pollution encountered. Moreover, in physical characteristics and chemical constituents the Ohio River water, in this region, differs materially from the water at Cincinnati or Louisville; and these differences might affect the efficiency of purification processes. However, so far as any inference is justified by the data at hand, it would appear possible to deliver safe effluents from the Ohio River in the zones above Wheeling and Steubenville.

Further Studies Required.—Obviously, there are further questions concerning the safety of water supplies from the Ohio River which are vital to future policy—for example, whether the plants in actual operation have ample margins of safety to guarantee consistency of performance; and what effect a given increase of pollution in the river may be expected to have upon the quality of their effluents. These matters require thorough study from other angles, including careful analysis of the management and operating costs of filtration plants under the different ranges of pollution encountered at different seasons, as well as analyses of their effluents.

During 1915 and 1916 such a study was made of the filtration plants at Cincinnati and Louisville, with a view to determining the relation between increasing bacterial pollution of the raw water and bacteriological quality of the effluent. The results [6] indicate that the relation between raw water and effluent in respect of bacterial

[5] The water at Portsmouth is somewhat more highly polluted than at Cincinnati and probably somewhat more dangerous, due to the nearer proximity of a number of sewered cities above Portsmouth.

[6] Streeter, H. W., The Loading of Filter Plants, Weekly Public Health Reports, Washington, Vol 37, No. 13, March 31, 1922. Reprint from Public Health Reports, No. 737.

content at these plants is quite definite, and that it is capable of fairly accurate expression by a formula of the type:[7]

$$E = cR^n$$

However, it is not established that this or any other law applies to the average results of rapid sand filters in general.

Further studies of this and other questions relating to the operation of filter plants treating water of high pollution are now in (1924) progress. Detailed data on operation and results are being collected from 17 filtration plants, including 10 upon the Ohio River, of which 4, at East Liverpool, Steubenville, and Portsmouth, Ohio, and Henderson, Ky., have been installed since 1914. At the same time studies are being made with an experimental filter plant at Cincinnati. The results of these investigations, combined with studies of the morbidity and mortality experience of the Ohio River cities which have installed filtration plants in recent years should make it possible, in the near future, to form a more confident judgment of the present condition of the Ohio River as affecting filtered water supplies taken from it. In the meantime, the experience of Cincinnati and Louisville indicates that from the standpoint of procuring satisfactory water supplies the pollution of the Ohio River at their intakes, high as it is, has not yet become intolerable.

POLLUTION IN ZONES IMMEDIATELY BELOW LARGE CITIES

As has been previously noted (see pp. 69, 71, Table 40) the urban population of the Ohio watershed is concentrated to a remarkable extent along the course of the main stream, about 40 per cent of the total being comprised in cities situated immediately upon the Ohio River itself. The urban population along the banks of the Ohio is again concentrated largely in five large centers, Pittsburgh, Wheeling, Cincinnati, Louisville, and Evansville. Three of these centers, the metropolitan districts of Pittsburgh, Cincinnati, and Louisville, with a combined population (1915) of 1,720,000, comprise approximately 75 per cent of the urban population along the course of the Ohio, and nearly 30 per cent of that on the entire drainage area. These cities are therefore, by reason of their size and location, the most important individual units in the sewage pollution of the river.

Conditions of pollution existing in the river immediately below these large cities are of special interest because it is in these zones

[7] In which (E) represents the bacterial content of the effluent, (R) that of the influent, (c) and (n) being constants defining, respectively, the average efficiency of purification and the relative constancy of effluent under different conditions of loading. The values of these constants as determined for the Cincinnati and Louisville filtration plants are:

For gelatin counts	$c=4.41$, $n=0.27$
For agar counts	$c=0.23$, $n=0.55$
For B. coli index	$c=0.29$, $n=0.30$

that the river reaches its maximum of pollution; and because the conditions below each city, when compared with those immediately above, afford a measure of the effect which that city has had upon the pollution of the stream. This in turn makes it possible to estimate with some precision the improvement which would result from the elimination of all or any given part of the pollution from this particular source. Again, the zones of maximum pollution below the large cities are the most advantageous points of departure from which to take up studies of natural purification.

For reasons already stated (Section IV, p. 90) it was found impracticable to establish any sampling stations in the vicinity of Evansville, hence no data are available bearing directly upon the pollution of the river in the vicinity of that city, but regarding the other four large cities the required information is available from the examination of samples collected from the river immediately above and immediately below each city.

For convenience of reference, the monthly mean results of 37° agar counts and of *B. coli* tests at the sampling stations below Pittsburgh, Wheeling, Cincinnati, and Louisville are assembled in Tables Nos. 96 and 97.[8] These tables summarize the results from two stations below each city and from a third station below Cincinnati, the upstream station in each district being the station next below all sewer outlets of the district, and the lower stations being located below that at distances as indicated by the station numbers.[9] In the Pittsburgh district, between stations 3 and 11, and in the Wheeling district between stations 97 and 104, the river receives some additional urban sewage; but no wastes of any account are discharged into the stream between stations 475 and 488, in the Cincinnati district, or between stations 611 and 619, below Louisville.

[8] The results of gelatin counts at these stations, which are of the same general significance as the agar counts, are not reproduced here, but may be found in the basic tables.

[9] Each station being numbered according to its distance, in miles, from Pittsburgh.

TABLE NO. 96.—*Summary of mean monthly agar counts at sampling stations immediately below the cities of Pittsburgh, Wheeling, Cincinnati, and Louisville*

Sampling stations	Bacteria per cubic centimeter on agar at 37° C											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Pittsburgh:												
Station No. 3	440	1, 010	*950	*900	*2, 440	*15, 200	*10, 600	*14, 500	*41, 100	*53, 900	----------	----------
Station No. 11	----------	----------	280	600	1, 280	10, 200	3, 420	2, 000	3, 060	1, 300	----------	----------
Wheeling:												
Station No. 97	----------	----------	----------	----------	*627	*2, 680	*3, 800	*4, 330	*1, 570	*2, 460	----------	----------
Station No. 104	----------	----------	----------	----------	414	2, 530	2, 000	2, 740	1, 000	1, 500	----------	----------
Cincinnati:												
Station No. 475—												
1914	*3, 080	*1, 820	*3, 480	4, 350	*28, 000	*237, 000	*147, 000	*262, 000	*170, 000	*203, 000	*198, 000	25, 700
1915	*3, 120	*1, 820	*2, 480	64, 100	54, 700	27, 800	*57, 300	51, 900	*60, 300	39, 200	72, 700	*5, 930
1916	3, 800	*3, 300	*4, 000	4, 600	27, 500	27, 200	*86, 700	74, 200	*151, 900	*216, 100	102, 200	*12, 300
Station No. 482—												
1914	1, 560	1, 750	1, 570	*5, 000	20, 200	91, 800	82, 700	41, 100	70, 700	48, 900	67, 700	14, 800
1915	2, 640	1, 550	1, 160	53, 300	54, 100	24, 900	37, 700	35, 400	56, 700	*70, 900	*88, 700	4, 220
1916	*3, 900	2, 900	3, 700	5, 200	30, 400	20, 100	63, 600	*97, 350	142, 200	98, 100	*118, 700	8, 640
Station No. 488—												
1914	----------	----------	----------	4, 940	24, 900	50, 800	29, 900	29, 800	50, 800	27, 900	79, 300	*45, 400
1915	2, 630	1, 250	1, 470	*78, 400	*58, 400	*35, 900	42, 200	*54, 500	54, 900	69, 600	61, 100	4, 180
1916	3, 620	2, 850	3, 600	*5, 280	*37, 200	*28, 200	60, 000	83, 560	49, 000	54, 100	118, 000	9, 680
Louisville:												
Station No. 611—												
1914	3, 200	5, 030	*3, 630	2, 860	3, 890	26, 300	10, 100	41, 000	30, 300	55, 800	7, 970	3, 350
1915	*3, 150	2, 290	*617	350	----------	----------	----------	----------	----------	----------	----------	----------
Station No. 619—												
1914	----------	----------	3, 330	*2, 880	*5, 600	*52, 100	*34, 400	*77, 000	*42, 600	*57, 900	*26, 900	*3, 600
1915	2, 690	*2, 460	597	*3, 140	----------	----------	----------	----------	----------	----------	----------	----------

NOTE.—Maximum in each district, each month. designated by asterisk (*)

TABLE No. 97.—*Summary of mean monthly numbers of B. coli per cubic centimeter at sampling stations immediately below the cities of Pittsburgh, Wheeling, Cincinnati, and Louisville*

Sampling stations	Year	Summary of mean monthly numbers of B. coli per cubic centimeter											
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Pittsburgh:													
Station No. 3	1914	86	226	*169	*88	*196	*220	*127	*110	*726	*225	----	----
Station No. 11	1914	----	----	10	20	76	37	15	34	110	148	----	----
Wheeling:													
Station No. 97	1914	----	----	----	----	*84	*118	*161	151	*92	113	----	----
Station No. 104	1914	----	----	----	----	72	92	35	*212	49	*186	----	----
Cincinnati:													
Station No. 475	1914	*131	*166	*136	135	188	*2, 930	*6, 190	*9, 410	*7, 230	*3, 970	*3, 150	*923
	1915	*144	*186	*363	*1, 090	1, 730	1, 320	*3, 300	*1, 800	1, 380	567	819	*270
	1916	117	*125	55	*118	*601	617	*1, 037	1, 313	2, 300	*5, 689	*4, 710	*317
Station No. 482	1914	65	104	114	*182	251	1, 220	2, 420	1, 120	2, 590	1, 500	1, 480	177
	1915	114	139	65	868	*1, 860	*1, 440	1, 760	1, 100	*1, 850	1, 320	*1, 090	111
	1916	112	123	*132	78	586	326	742	*2, 097	*3, 100	4, 797	1, 595	139
Station No. 488	1914	----	----	----	67	*375	1, 330	1, 770	393	2, 550	929	1, 600	162
	1915	111	70	70	946	1, 230	1, 200	1, 470	1, 180	1, 330	1, 860	815	151
	1916	*125	92	74	102	546	340	767	1, 880	1, 470	1, 750	3, 050	230
Louisville:													
Station No. 611	1914	180	165	128	133	*233	255	784	971	709	*798	183	56
	1915	*52	*41	23	27	----	----	----	----	----	----	----	----
Station No. 619	1914	----	----	*182	*175	223	*456	*1, 230	*1, 190	*1, 380	755	*344	*141
	1915	43	34	*24	*63	----	----	----	----	----	----	----	----

NOTE.—Maximum in each district, each month, designated by asterisk (*).

It will be noted from these tables that in the Pittsburgh and Wheeling districts the pollution, as indicated by agar counts, is uniformly higher at the sampling station next below the sewer outlets than at the station next downstream.[10] Irregularities in the *B. coli* index, which is occasionally higher at station 104 than at station 97, are of no great significance, considering that the quantitative estimation of *B. coli* is subject to a rather large error.

At Cincinnati and at Louisville the case is different. At Louisville the highest pollution is ordinarily shown, not at station 611 which is immediately below the sewer outlets, but at station 619, eight miles downstream. The apparent increase in bacterial content of the river between these two stations can not be accounted for by wastes added below station 611, since these are negligible in amount. In all probability the increase is due, at least in part, to a sampling error of constant tendency at 611, the sewage of Louisville not having become well mixed with the river water, as it passes this station so that a mean of the three samples taken from the cross section does not show its full effect nor truly represent the cross section. The apparent increase between stations 611 and 619 may, therefore, be reasonably attributed to the better mixture which has taken place by the time the water reaches station 619, it being evident from comparison of the three sampling points on this section that the mixture here is much more uniform than at station 611. As the time of flow elapsing between stations 611 and 619 may be as great as 10 or 12 hours at low river stages, it is possible that natural processes of purification may have somewhat reduced the pollution of the river by the time it reaches station 619; but even so the results at this station are generally more reliable than are observations at station 611.

In the zone immediately below Cincinnati, it will be noted that the highest bacterial counts are observed sometimes at station 475, sometimes at station 482 or at 488, sometimes even at station 492, which is not shown in these tables as it is located below the Miami River. As it occurs in these tables, the fluctuation of the maximum bacterial count from station to station appears quite irregular and consequently not to be explained by a sampling error of constant tendency. However, as is shown more fully in a later discussion, the location of the maximum count bears a fairly definite relation to river stage, falling generally at station 475 at river stages under 5 feet; at station 482 with river stages from 5 to 8 feet; and at station 488 or 492 when river stages are still higher. It may be, therefore, that the apparent bacterial increase sometimes noted in passages downstream from station 475 is due to a sampling error similar to that noted at Louisville, but bearing a definite relation to river stage. Other possible explanations of this tendency to higher

[10] With one single exception this is true also as regards the gelatin counts.

counts below station 475 are discussed later (pp. 273–277). For present purposes it suffices to note that, for measuring the effect which the city has upon pollution of the river, the observation which shows the highest pollution is the most reliable, for sampling errors tending to give a result less than the true mean are more probable than errors tending to give an excessive result.

Seasonal variations in pollution.—While Tables Nos. 96 and 97 serve to indicate the range and variation of bacterial pollution as observed from month to month, the broader tendencies of variation in relation to discharge and population contributing to the immediate pollution are shown better when the data are summarized as in Table No. 98 following:

TABLE NO. 98.—*Summary of mean discharge, population immediately above, total urban population on watershed above, and average number of bacteria per cubic centimeter at stations immediately below Pittsburgh, Wheeling, Cincinnati, and Louisville, during two periods in the year 1914*

	Mean discharge (second-feet)	Second-feet per thousand—		Average number of bacteria per centimeter	
		Of population immediately above	Of urban population on whole watershed above	Agar count	B. coli
Period January–May, 1914:					
Below Pittsburgh, station 3	51,900	45	18	1,120	153
Below Cincinnati, station 475	161,300	271	21	8,150	161
Below Louisville, station 619	193,000	630	21	4,070	187
Period June–October, 1914:					
Below Pittsburgh, station 3	4,640	4.02	1.64	27,100	272
Below Wheeling, station 97	5,680	64	1.38	2,970	128
Below Cincinnati, station 475	17,900	30	2.3	204,000	5,480
Below Louisville, station 619	22,700	72	2.47	52,800	900

As will be noted from this summary, the bacterial pollution below each of the cities where observations extended over a sufficient period to warrant comparisons was much less during the period of high discharge from January to May than during the summer period of low discharge. This is as expected, in view of the greater dilution afforded in winter, but the differences in bacterial content are by no means directly proportionate to differences in discharge. For example, the discharge during the months June to October is about one-tenth of the discharge at corresponding stations during the period from January to May; but the agar counts below Pittsburgh and Cincinnati are increased more than twentyfold in the former period as compared with the latter; and at Louisville also the disproportion is similar though not quite so great. The *B. coli* index below Cincinnati is likewise increased during the low water months much more than is accounted for by the diminished dilution; but at Pittsburgh

and Louisville the case is reversed, the increase in pollution being less than would be expected from the decrease in dilution.

Relative intensity of pollution below different cities.—The most striking fact shown, however, is that the pollution is much less intense below Pittsburgh than it is below Cincinnati or even below Louisville, notwithstanding that the population contributing to the immediate pollution at Pittsburgh is considerably greater than at Cincinnati; and the discharge at Pittsburgh is less than one-third that observed at Cincinnati. From the ratios of discharge to sewered population immediately above, as shown in Table No. 98, it would be expected that the pollution at Pittsburgh would be at least five or six times as great as below Cincinnati, whereas it is consistently and very materially less. Similarly, the pollution below Wheeling is much less than below Louisville, although from the ratios of discharge to sewered population it would be expected to be somewhat higher. This disproportionately small effect of the sewage from Pittsburgh and Wheeling upon the bacterial content of the upper Ohio River is one of the most remarkable facts noted in this study, and is undoubtedly of primary sanitary importance. As it is discussed in more detail later, it need merely be noted here.

Proportion which the bacteria added to the river in the sewage of large cities are of the total numbers found in the river immediately below.—By comparing the bacterial content of the river as observed immediately below each city with similar observations made at a sampling station immediately above the city, it is possible to measure the increase in pollution directly attributable to the inflow of sewage and other drainage from the intervening urban area, provided of course that no other drainage is received by the stream between these stations.

At Pittsburgh the sampling stations required for such comparison were located above the city on the Allegheny (station A–7) and Monongahela (station M–12) Rivers, respectively, and immediately below the city on the Ohio River at station No. 3. The increase in numbers of bacteria per cubic centimeter due to the inflow of wastes between these points is shown by the difference between results at station 3 and the average of results during a corresponding period at stations A–7 and M–12, weighted according to discharge.

The increase in passage past Wheeling is shown directly by the difference between the corresponding results at station 97, below the city, and station 88, above, the discharge at these two stations being practically identical. Likewise at Louisville the effect of the city's waste may be measured by the difference between observations at the sampling station below the city which shows the highest pollution (either station 619 or station 611) as compared with station 598, above the city, since no tributary measurably affecting discharge enters between these stations.

nati, two tributaries, the Little Miami and the Licking, into the Ohio between station 461, which is above the city, and station 475, which is immediately below. Sampling stations were, however, maintained on these tributaries above such pollution as they received from the Cincinnati metropolitan district,[11] and their discharges were measured. An average of results on these tributaries and at station 461, weighted according to respective discharges, may therefore be taken as representing the pollution above the city. This may then be compared with observations at the station below Cincinnati which shows the highest pollution, whether this be station 475, 482, or 488. The calculations which are given hereafter are based, for each month, upon the station below Cincinnati, which showed the maximum pollution for that month.

Further details regarding the sampling stations referred to and their relation to near-by sources of pollution are given in Section IV, pp. 98–104. Reference should also be made to Figure No. 14, page 69, showing the relative positions of cities, tributaries, and sampling stations, and to Table No. 41, Section III.

The part which the wastes from these several districts play in contributing to the bacterial pollution of the river as observed immediately below each city is shown in Table No. 99, in which the increase in number of bacteria per cubic centimeter between the upper and lower stations of each district is expressed, for each month, as a percentage of the total number observed at the lower station.

TABLE No. 99.—*Percentages which the bacteria added to the Ohio River in passage past the metropolitan districts of Pittsburgh, Wheeling, Cincinnati, and Louisville are of the total numbers observed in zones immediately below these districts, by months, 1914, 1915, and 1916.*

River.	Years.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Gelatin counts:													
Below Pittsburgh:	1914	-----	-----	26	33	14	38	44	23	81	87	-----	-----
Below Wheeling	1914	-----	-----	-----	-----	-----	-----	86	79	67	91	-----	-----
Below Cincinnati	1914	24	1.4	15	61	89	99.2	99.6	98.2	99.4	98.4	99.9	93.4
	1915	15	26	46	98.9	91	84	81	91	90	95	94	29
	1916	(a)	(a)	(a)	27	92.8	82	97.9	93.4	98.2	99.1	99.5	53
Below Louisville	1914	-----	14	25	52	66	98.2	99.1	97	97	98.1	99.6	37
	1915	74	(a)	18	89	-----	-----	-----	-----	-----	-----	-----	-----
Agar counts:													
Below Pittsburgh	1914	-----	-----	91	64	(a)	5	42	30	74	92	-----	-----
Below Wheeling	1914	-----	-----	-----	-----	29	43	83	83	75	91	-----	-----
Below Cincinnati	1914	84	1.9	72	90	98.8	99.7	99.7	99.2	99.2	98.1	99.9	90.2
	1915	(a)	25	76	99.8	96	92	91	93	95	97	97	47
	1916	18	40	23	85	98.1	92.1	98.9	96.4	99.1	99.1	99.5	85
Below Louisville	1914	15	2.6	23	(a)	50	98.9	99.4	98.4	98.8	98.8	99.6	33
	1915	12	9	12	93	-----	-----	-----	-----	-----	-----	-----	-----
B. coli:													
Below Pittsburgh	1914	-----	-----	92	86	94	86	82	68	90	91	-----	-----
Below Wheeling	1914	-----	-----	-----	-----	67	75	55	77	53	91	-----	-----
Below Cincinnati	1914	82	70	85	86	95	99.6	99.9	99.2	99.5	99.5	99.8	88
	1915	70	77	95	99.5	95	96	95	93	96	96	95	84
	1916	78	78	84	88	97.9	90.4	98.8	97.7	99.4	99.7	99.8	78
Below Louisville	1914	83	48	82	38	58	98	99.9	91	98.6	98.6	98.8	79
	1916	31	(a)	33	95	-----	-----	-----	-----	-----	-----	-----	-----

[a] Count below the city less than above.

[11] The sampling station on the Little Miami was subject to some pollution by sewage from a section of the Cincinnati metropolitan district entering through Duck Creek, above the sampling station.

As seen from this table, the bacteria added in the wastes from Cincinnati and Louisville are sufficient to account always for more than 80 per cent, usually more than 90 per cent, and frequently more than 99 per cent of the total numbers found in the river immediately below these cities during the months from June to November.

During the winter and spring months, when the river is generally at higher stages, the indicated additions from Cincinnati and Louisville fall at times to less than 20 per cent, and occasionally there is an indicated decrease in the numbers of bacteria in passage past the city. This must, of course, be attributed to observational error, since it is altogether unlikely that an actual decrease in bacteria ever takes place in passage past these cities. If the probable error of a monthly mean of bacteriological observations at a sampling station be assumed to be ± 10 per cent, which is a reasonable figure in view of the analyses of experimental errors presented in the discussion of chemical data (see Section V, pp. 129–142), then an occasional error of even 30 per cent or more is to be expected, and an error of this magnitude could readily account for the apparent decrease occasionally noted in passage past Cincinnati and Louisville at high river stages.

It is a rather striking fact, as indicated by these data, that during moderate and low river stages the bacterial flora of the river is almost entirely renewed in passage past Cincinnati, and again at Louisville. As the river leaves each of these cities the bacteria which it carries are almost entirely those which have been added in the city's sewage, with only a small, almost negligible proportion brought down from sources above. This must be true at various other points on the river system, as for instance, where smaller cities discharge their sewage into tributaries of the Ohio. So it would appear that the bacterial flora of the river, at least those species included in standard determinations, may be almost completely destroyed and renewed several times between its headwaters and its mouth.

ACTUAL NUMBERS OF BACTERIA ADDED IN CITY WASTES

Given the discharge of the river in second-feet and the numbers of bacteria per cubic centimeter, these data may readily be converted into terms of the actual numbers of bacteria contained in the river, or rather the numbers carried past a given section in a given period of time. Since 1 cubic foot = 28,317 cubic centimeters, a content of one bacterium per cubic centimeter in 1 cubic foot = 28,317 bacteria, and an average of one bacterium per cubic centimeter in a flow of 1 cubic foot per second (1 second-foot) represents a discharge of 28,317 bacteria per second = 2,446,589,000 bacteria per diem. Hence the total number of bacteria carried past a given section of river in a day = discharge, in second-feet, $\times$ bacteria per cubic centimeter $\times$ 2,446,589,000. As this gives very unwieldy numbers, it is convenient to

use, for the unit of bacterial discharge the number of bacteria which, if discharged constantly into a stream flowing at the rate of 1 second-foot would give a density of 1,000 bacteria per cubic centimeter. Given the number of bacteria per cubic centimeter and the discharge at any point the observations can be converted into terms of this "quantity unit" by the simple relation:

$$\frac{\text{Discharge, in second-feet} \times \text{bacteria per c. c.}}{1000} = \text{Numbers of bacteria}$$

in "quantity units."

The "quantity units" in which this result is expressed may then be converted into bacteria per day by the multiplying factor 2,446,-589,000,000; but for most purposes this conversion is not necessary, and it answers the requirements to express bacterial discharge in the less unwieldy "quantity units."

Since the discharge of the Ohio River varies widely in different river zones, and in the same zone from month to month, the bacterial pollution contributed by the four large cities may be more significantly expressed in these "quantity units" which measure the actual number of bacteria added, taking account of volume as well as density. The increase in the bacterial content of the Ohio river in passage past Pittsburgh, Wheeling, Cincinnati and Louisville, respectively is accordingly shown in these "quantity units" in Tables Nos. 100, 101, and 102 following.

TABLE No. 100.—*Increase in bacterial pollution of the Ohio River in passage past metropolitan districts as shown by quantity units added between designated sampling stations, based on gelatin counts, monthly means*

Month	Pittsburgh station A-7 and M-12 to station 3	Wheeling, station 88 to 97	Cincinnati [1]				Louisville,[1] station 598 to 619—1914
			Station 461 to 475			Average three years	
			1914	1915	1916		
January	----------	----------	637,000	[2] 475,000	[3] Decrease	556,000	[4] 244,000
February	----------	----------	[5] 50,000	[2] 917,000	[3] Decrease	483,500	[4] 796,000
March	111,000	----------	540,000	482,000	[3] Decrease	511,000	[4] 582,500
April	[6] 85,660	----------	[2] 1,915,000	[7] 3,594,000	[2] 684,000	2,064,333	[4] 854,000
May	32,300	----------	[7] 2,457,000	2,941,000	[5] 3,935,000	3,111,000	854,000
June	34,100	----------	2,523,000	[2] 2,237,000	[2] 3,926,000	2,895,333	1,014,000
July	12,600	24,100	1,904,000	2,788,000	[5] 2,247,000	2,313,000	719,000
August	3,620	11,800	1,954,000	[2] 3,771,000	[5] 2,604,000	2,776,333	1,125,000
September	96,300	4,950	1,664,000	[5] 2,355,000	2,149,000	2,056,000	922,000
October	10,100	8,320	1,932,000	[7] 6,028,000	4,654,000	4,204,667	1,204,000
November	----------	----------	2,917,000	[5] 6,635,000	[2] 3,805,000	4,452,333	721,000
December	----------	----------	[7] 6,999,000	1,174,000	[7] 1,165,000	3,112,667	570,000
Averages:							
January-March	111,000	----------	409,000	624,667	----------	516,833	540,800
April-May	58,980	----------	2,186,000	3,267,500	2,309,500	2,587,667	831,200
June-October	31,344	12,293	1,995,400	3,435,800	3,116,000	2,849,067	996,800
Year	----------	----------	2,124,333	2,783,083	2,226,625	2,378,014	796,700

[1] Except as otherwise indicated quantity units at Cincinnati are calculated from results at station 475; and at Louisville from results at station 619.
[2] Calculations based on results at station 492 with correction for effect of Miami River.
[3] Mean of values for corresponding months of 1914 and 1915 interpolated in calculating yearly average.
[4] Mean for years 1914 and 1915.
[5] Calculations based on results at station 482, maximum being at this section.
[6] Calculations based on results at station No. 5, there being no data available for station 3.
[7] Calculations based on results at station 488, maximum being at this section.

TABLE No. 101.—*Increase in bacterial pollution of the Ohio River in passage past metropolitan districts as shown by quantity units, added between designated sampling stations, based on agar counts, monthly means*

Month	Pittsburgh, stations A–7 and M–12 to station 3	Wheeling, stations 88 to 97	Cincinnati[1]				Louisville[1] station 598 to 619—1914
			Stations 461 to 475			Average three years	
			1914	1915	1916		
January	------------	------------	258,000	[2] Decrease	[3] 213,000	235,500	[4] 66,400
February	------------	------------	59,600	[5] 118,000	292,000	156,533	[4] 48,400
March	49,500	------------	398,000	160,000	184,000	247,333	[4] 85,100
April	[6] 45,800	------------	[5] 1,700,000	[7] 3,257,000	[5] 1,018,000	1,991,667	[4] 141,000
May	Decrease.	10,000	[5] 5,081,000	[7] 3,125,000	[5] 3,792,000	3,999,333	415,000
June	6,780	11,700	4,965,000	[7] 2,476,000	[5] 3,418,000	3,619,667	1,484,000
July	24,100	20,800	2,773,006	3,907,000	4,046,000	3,575,335	790,000
August	16,000	16,800	3,949,000	[5] 3,569,000	[3] 4,275,000	3,931,000	1,386,000
September	102,000	5,320	2,950,000	2,971,000	2,816,000	2,912,333	880,000
October	83,000	5,550	3,371,000	[3] 4,833,000	5,183,000	4,462,333	1,281,000
November	------------	------------	2,330,000	[3] 5,025,000	[3] 2,156,000	3,170,333	329,000
December	------------	------------	[7] 3,163,000	415,000	664,000	1,414,000	116,000
Averages:							
January–March	49,500	------------	238,533	139,000	229,667	202,400	66,630
April–May	45,800	10,000	3,390,500	3,191,000	2,405,000	2,995,500	278,000
June–October	46,376	12,034	3,601,601	3,551,200	3,947,600	3,700,134	1,164,200
Year	------------	------------	2,583,134	2,507,625	2,338,003	2,476,254	585,160

[1] Except as otherwise indicated calculations at Cincinnati are based upon results at station 475; and at Louisville from results at station 619.
[2] Mean of values for January, 1914, and 1916, interpolated in calculating average for the year.
[3] Calculations based on results at station 482, maximum being reached at this section.
[4] Mean for years 1914 and 1915.
[5] Calculations based on results at station 492, with correction for effect of Miami River.
[6] Calculations based on results at station No. 5, there being no data available for station No. 3.
[7] Calculations based on results at station 488, maximum being reached at this section.

TABLE No. 102.—*Increase in bacterial pollution of the Ohio River in passage past metropolitan districts as shown by quantity units added between designated sampling stations, based on B. coli determinations, monthly means*

Month	Pittsburgh, stations A–7 and M–12 to station 3	Wheeling, stations 88 to 97	Cincinnati[1]				Louisville,[1] stations 598 to 619—1914
			Stations 461 to 475			Average three years	
			1914	1915	1916		
January	----------	----------	10,700	18,400	[2] 32,900	20,667	[3] 9,820
February	----------	----------	19,800	[2] 42,500	21,300	27,867	[3] 17,700
March	9,210	----------	18,600	28,900	22,700	23,400	[3] 14,800
April	[4] 6,020	----------	[5] 38,600	45,100	[2] 31,300	38,333	[3] 11,250
May	7,750	3,120	[6] 44,700	[5] 99,100	56,900	66,900	20,000
June	1,770	916	61,300	[2] 119,000	[2] 72,100	84,133	12,800
July	560	590	117,000	235,000	48,500	133,500	28,400
August	280	763	142,000	91,500	[5] 93,600	109,033	19,900
September	2,210	220	90,300	[5] 92,300	[5] 57,600	80,067	28,400
October	390	420	284,000	[6] 126,000	137,000	182,333	17,600
November	----------	----------	37,000	[5] 60,300	85,600	60,967	4,180
December	----------	----------	71,700	33,800	15,800	40,433	10,700
Averages:							
January–March	9,210	----------	16,367	29,933	25,633	23,978	14,107
April–May	6,885	3,120	41,650	72,100	44,100	52,617	15,625
June–October	1,042	582	138,920	132,760	81,760	117,813	21,420
Year	----------	----------	77,975	82,658	56,275	72,303	16,296

[1] Except as otherwise indicated, Quantity Units at Cincinnati are calculated from results at Station 475, and at Louisville from results at station 619.
[2] Calculations based on results at station 492, with correction for effect of Miami River.
[3] Mean for the years 1914, and 1915.
[4] Calculations based on results at station No. 5, there being no data available for station No. 3.
[5] Calculations based on results at station 482, maximum being reached at this section.
[6] Calculations based on results at station 488, maximum being reached at this section.

Seasonal variation in total numbers of bacteria added.—Before undertaking to compare the four cities with respect to the numbers of bacteria which they contribute to the river it may be noted that both at Cincinnati and Louisville, the only districts where observations were continued through a full seasonal cycle, the "quantity units" of bacteria vary widely from month to month. It is readily seen, too, that these are not random variations, such as might be expected from observational error; but that they show an orderly relation to season, the tendency being to much higher quantities in the summer and autumn than during the winter and spring months, and that they are in a general way parallel in the two districts. Moreover, the range of variation is far beyond that which may reasonably be attributed to experimental error.

The range and sequence of these variations in the two districts are better illustrated in Table No. 103, in which the quantities observed in each month are expressed as percentages of the annual average. With the data thus reduced to a common denominator, it is readily seen that the variations at Cincinnati in successive years correspond quite closely in time and range, and are quite similar to the variations observed at Louisville.[12]

TABLE NO. 103.—*Seasonal variation in quantity units of bacteria added to the Ohio River in passage past Cincinnati (1914, 1915, 1916), and Louisville (1914); ratios of quantities in each month to corresponding yearly average (100)*

Months	Gelatin count					Agar count					B. coli				
	Cincinnati				Louisville, 1914[1]	Cincinnati				Louisville, 1914[1]	Cincinnati				Louisville, 1914[a]
	1914	1915	1916	Three-year average		1914	1915	1916	Three-year average		1914	1915	1916	Three-year average	
Year	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
January	30	16	-----	23	31	10	-----	9	10	11	14	22	58	29	60
February	2	33	-----	18	100	2	5	12	6	8	25	51	38	39	109
March	25	17	-----	21	73	15	6	8	10	15	24	35	40	32	91
April	90	129	31	87	101	66	130	44	80	24	50	55	56	53	69
May	116	106	177	131	107	197	125	162	161	71	57	120	101	93	123
June	119	80	176	122	127	192	99	146	146	254	79	144	128	116	79
July	90	100	101	97	90	107	156	173	144	135	150	284	86	185	174
August	92	136	117	117	141	153	142	183	159	237	182	111	166	151	122
September	78	85	97	86	116	114	118	120	118	150	116	112	102	111	174
October	91	217	209	177	151	131	193	222	180	219	364	152	243	252	108
November	137	238	171	187	90	90	200	92	128	56	47	73	152	84	26
December	329	42	52	131	72	122	17	28	57	20	92	41	28	56	66
January to March, inclusive	19	22	-----	21	68	9	6	10	9	11	21	36	45	33	87
April and December	209	86	42	109	87	94	73	36	69	22	71	48	42	54	67
May to November, inclusive	103	137	150	131	118	141	148	157	148	160	142	142	140	142	115

[a] Ratios for months January to April, inclusive, at Louisville calculated from mean values for 1914 and 1915. No observations at Louisville after April, 1915.

[12] This can hardly be said of the monthly variations in *B. coli* at Louisville, which are quite irregular; but appplies fairly to the gelatin and agar counts.

From the records at Cincinnati, which cover three full years, an average ratio has been calculated for each month. These average ratios are plotted in Figure No. 27, from which it may be seen that the cycles of seasonal variation in the gelatin, agar, and *B. coli* groups, respectively, are similar in their general tendencies, though differing in some details.

From the foregoing it may be concluded that there is a regular cyclic seasonal variation in the total bacterial content of the combined wastes discharged into the Ohio River from both the Cincinnati and the Louisville metropolitan districts. This variation, which is evidenced alike in the gelatin count, agar count, and *B. coli* groups of bacteria, is most regular and of widest extent in the agar count group. In general, the bacterial content of the wastes is least during January, February, and March, and greatest during the months from June to October, inclusive, the summer average being more than ten times the winter average for the agar count group, and five times the winter average for the gelatin count and *B. coli* groups as observed at Cincinnati.

The cycle of variation is evidently more closely related to season than to hydrographic conditions, for in the corresponding months of 1914, 1915, and 1916, especially in the months from May to November, inclusive, hydrographic conditions in the Ohio River varied widely, notwithstanding which the cycle of bacterial variation was fairly constant in all three years. As the most prominent physical change associated with the seasonal cycle is that in temperature, it seems probable that the latter is the controlling factor in the bacterial cycle.

A similar seasonal variation in the *B. coli* content of the St. Clair, Detroit, Niagara, and St. Lawrence Rivers was noted in studies of the pollution of these waters by the sanitary experts of the International Joint Commission.[13] These rivers, being outlets of the Great Lakes, are of fairly constant discharge; and at the sections under consideration their pollution is due almost wholly to the sewage discharged from large cities immediately above. Therefore, in samples from these sections the numbers of *B. coli* per cubic centimeter are presumably in direct proportion to the absolute numbers (not merely the numbers per cubic centimeter) in the sewage from the cities above.

The bacteriological data referring to the above-mentioned rivers, the St. Clair, Detroit, Niagara, and St. Lawrence, as given in Table No. 104, are taken from the above-cited report (p. 9). Since the observations on these rivers covered only the months from May to September (1913), inclusive, the ratios for individual months are

[13] Pollution of Boundary Waters, Report of the Consulting Sanitary Engineer upon Remedial Measures, March, 1916. International Joint Commission, Washington, G. P. O., 1916.

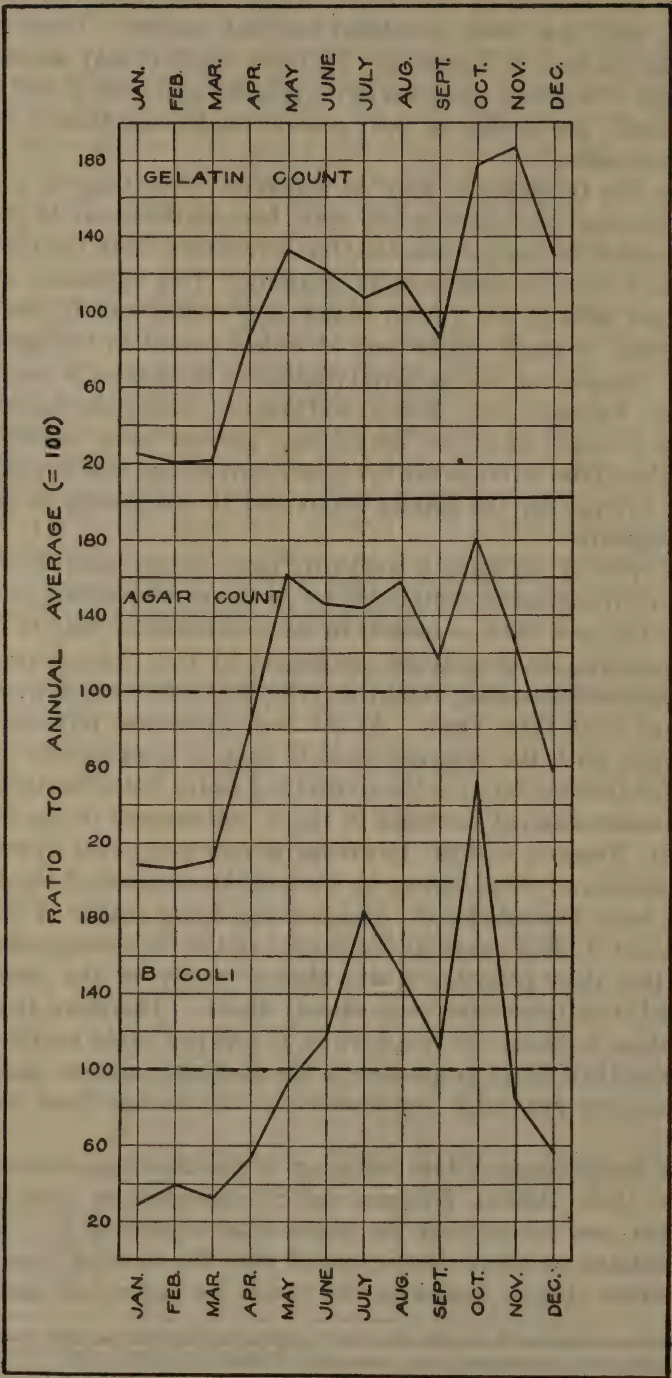

FIG. 27.—Seasonal variation in quantity units of bacteria added to the Ohio River in passage past Cincinnati. Ratios of quantities added each month to average for the year. Means for 1914, 1915, and 1916

calculated from the averages for this period, not from a full yearly average, and, for the sake of comparison, data for Cincinnati and Louisville are expressed in similar terms in this table.

TABLE No. 104.—*Seasonal variation in B. coli in international boundary waters (St. Clair, Detroit, Niagara, and St. Lawrence Rivers) and in wastes from Cincinnati and Louisville metropolitan districts*

[Percentages of average for period May–September, inclusive]

Month	International boundary waters	Cincinnati metropolitan district	Louisville metropolitan district
January	----------	22	45
February	----------	29	81
March	----------	25	68
April	----------	40	51
May	26	71	91
June	61	88	58
July	129	141	130
August	231	115	91
September	53	85	130
October	----------	192	80
November	----------	64	19
December	----------	43	49

Figure No. 28, illustrative of this table, shows the curves of seasonal variation of *B. coli* as observed in the international boundary waters and in the Ohio River at Cincinnati and Louisville, respectively. Although the curves do not correspond very closely in detail they show the same general tendency toward a relative increase of bacteria in July and August as compared to May, June, and September. The shape of the partial curve for the international boundary waters suggests that a full annual cycle there would show the characteristic summer increase beginning later and declining earlier than at Cincinnati and Louisville. If temperature is an important factor in the cycle, such a difference would be expected because of the difference in latitude between the Ohio River and the Great Lakes.

As regards the significance of the observed seasonal variation, Phelps, in presenting the report to the International Joint Commission, makes the following comment:[14]

"A quite unexpected and hitherto unnoted phenomenon has been shown, namely, a great increase in the bacterial evidence of pollution in the warmer months. This effect is shown so consistently in the work of the several laboratories, and upon the various rivers, that there can be no doubt of its reality. It is hardly to be believed that there is actual multiplication of the intestinal organisms in the streams themselves, although this possibility can not, with our present knowledge, be entirely eliminated. It is more probable that the bacterial content of the sewage shows a seasonal variation. Whether this be traceable to actual multiplication of intestinal bacteria within the sewers or to a greater per capita discharge of these organisms in the summer months can not be stated."

[14] Loc. cit., p. 9.

To this statement it may be added that the phenomenon has now been confirmed by independent observations upon another watercourse and that it is not peculiar to organisms of the *B. coli* group; but is exhibited likewise in the heterogeneous bacterial groups represented by the standard gelatin and agar counts, the variation in the latter being of wider range and somewhat more regular than in the *B. coli* group.

Beyond this, there is little to be added to Phelps' comment in the way of explanation. A possibility not suggested by him is, of

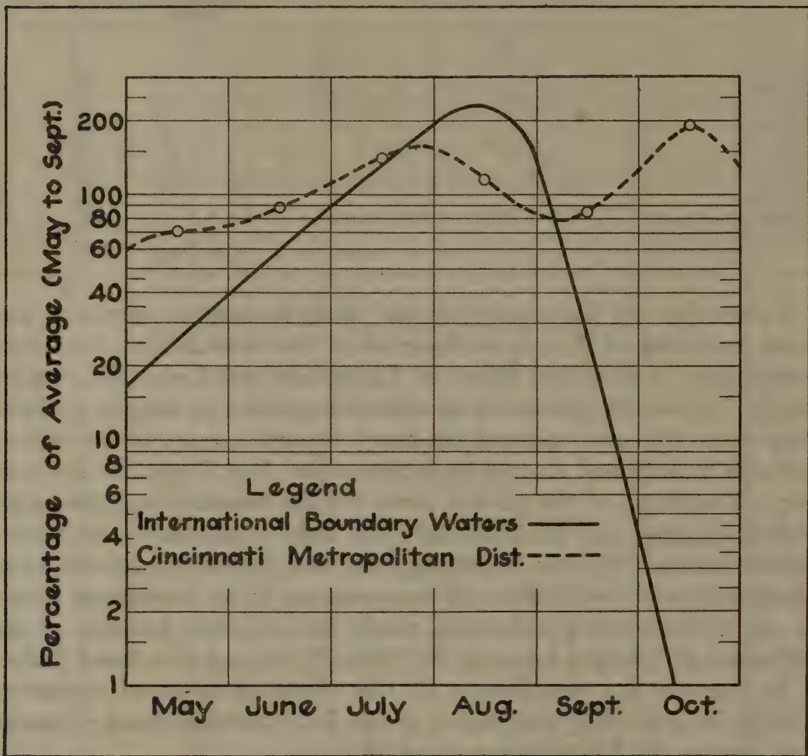

FIG. 28.—Seasonal variation in *B. coli* in International Boundary Waters and in wastes from Cincinnati metropolitan district

course, that during the colder months there may have been a rapid decrease of bacteria from the time that they were discharged into sewers until they reached the river sections where observations were made; but this does not seem likely. It seems more probable, as suggested by Phelps, that during the warmer months a considerable increase in bacteria takes place, either in the sewers or perhaps after their discharge into the stream.

In contrast to the observations at Cincinnati and Louisville are those at Pittsburgh, for even though the observations there do not

extend over a full year, they are sufficient to show that the tendency to seasonal variation is not the same as at Cincinnati and Louisville. With respect to the gelatin count and *B. coli* groups, there is a relative decrease rather than an increase during the summer months, while the agar count group shows an increase only in September and October. The observations at Wheeling all fall within what may be considered the "summer" period, hence there is no basis for a comparison with results in the winter. However, the general tendency is toward a decrease rather than an increase from May to October. This might be taken as indicating either that the seasonal variation noted in the Cincinnati and Louisville districts is due to some conditions peculiar to these districts, or that the absence of similar variations in the Pittsburgh district is due to peculiar local influences there. The former supposition is unlikely, since seasonal variations similar to those noted at Cincinnati and Louisville have been independently observed in the international boundary waters referred to above.[15] On the other hand, the river at Pittsburgh presents some very unusual conditions, in the presence of acid wastes which are obviously bactericidal, in the precipitation which results when the waters of the Monongahela, carrying acid iron wastes, meet the alkaline waters of the Allegheny, and in the long time intervals which elapse between the major sewer outlets and the nearest downstream sampling station (station No. 3) in low-water periods when dams are up. It may well be supposed that these influences may be sufficient to counterbalance or mask a normal tendency to a relative increase in bacterial content of sewage at Pittsburgh similar to that observed at Cincinnati and Louisville.

Numbers of bacteria in sewage of cities per capita of sewered population.—The populations tributary to the sewers which discharge into the Ohio River between sampling stations above and those below each large city as estimated with care from fairly accurate records, are as shown in the following summary.

Sewered population (1915)

Pittsburgh district, between stations A–7 and M–12 and station 3	710, 500
Wheeling district, between stations 88 and 97	59, 500
Cincinnati district, between stations 461 and 475	494, 300
Louisville district, between stations 598 and 611	179, 800

The data of Tables Nos. 100, 101, and 102 may therefore be reduced to a per capita basis, as in Table No. 105 following, which shows the numbers of bacteria added to the river per capita of sewered population per diem in passage past the metropolitan districts of Pittsburgh, Wheeling, Cincinnati, and Louisville, respectively.

[15] More recently, during 1920 and 1921, entirely similar seasonal variations have been noted in the bacterial content of the Chicago Drainage Canal, in the course of a study of the Illinois River by the Public Health Service.

TABLE No. 105.—*Actual numbers of bacteria, of gelatin count, agar count, and B. coli groups added to Ohio River by metropolitan districts of Pittsburgh, Wheeling, Cincinnati, and Louisville, per capita of sewered population*

[Annual and seasonal averages]

Metropolitan districts	Billions of bacteria per capita per diem								
	Gelatin count			Agar count			B. coli		
	Jan.–Mar.	June–Oct.	Year	Jan.–Mar.	June–Oct.	Year	Jan.–Mar.	June–Oct.	Year
Pittsburgh metropolitan district, stations A-7 and M-12, to station 3—Sewered population 710,500 (data for 1914)	382	108	--------	170	160	--------	31.7	3.6	------
Wheeling metropolitan district, stations 88 to 97—Sewered population 59,500 (data for 1914)	-------	505	--------	-------	495	--------	------	23.9	------
Cincinnati metropolitan district, stations 461–475—Sewered population 494,300 (data for three years 1914, 1915, and 1916)	2,558	14,102	11,770	1,002	18,314	12,256	119	583	358
Louisville metropolitan district, stations 598–619—Sewered population 179,800 (data for 1914)	7,359	13,564	10,841	907	15,842	7,962	193	291	222

In each of these areas there is a considerable population not served by sanitary sewers, which nevertheless contributes something to the pollution of the river by surface drainage, carried through storm water sewers and in natural channels. Also there are, in each district, fairly numerous industrial plants, contributing organic wastes which undoubtedly add to the bacterial pollution. No attempt is made, however, to take account of these sources in the calculations given, since there is no common denominator to which they can be reduced for inclusion with sewered population. It may only be said, in a general way, that the added pollution from unsewered areas would probably be relatively greatest in the Louisville district, and that from organic industrial wastes relatively greatest in the Cincinnati district. (See Table No. 48, p. 82, Section III.)

The per capita contributions from the Cincinnati and Louisville districts, whether calculated on the basis of gelatin counts, agar counts, or *B. coli* are of the same order of magnitude; and may be considered in fairly close agreement.[16] Moreover, the observations at Cincinnati during three successive years are in close agreement, as shown in Tables Nos. 100, 101, and 102.

Small ratio of bacteria to sewered population in the Pittsburgh and Wheeling districts.—In the Pittsburgh and Wheeling districts the re-

[16] These figures also correspond quite closely to similar calculations for the Sanitary District of Chicago, based upon observations during 1921 and 1922 at the lower end of the Chicago Drainage Canal. The numbers of bacteria in billions discharged through the drainage canal per diem, per capita of sewered population contributing were found to be:

	January–March	June–October
Gelatin count	4,086	24,186
Agar count	561	23,969
B. coli count	32	406

sults are entirely different. As shown in Table No. 105, and in Figure 29, the per capita contribution of bacteria from these districts is only a small fraction of that from Cincinnati and Louisville during corresponding seasonal periods. Thus, during the months from June to October, the per capita bacterial pollution from the Pittsburgh district was consistently less than 1 per cent, and from the Wheeling district less than 5 per cent of that from Cincinnati. In the winter months, January to March, when no data are available for Wheeling,

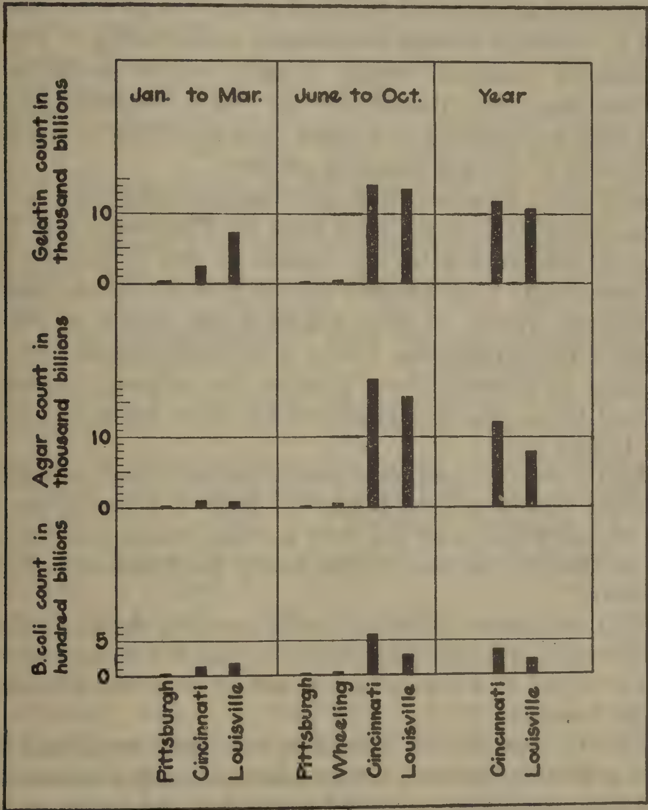

FIG. 29.—Numbers of bacteria per capita of sewered population added to the river by metropolitan districts of Pittsburgh, Wheeling, Cincinnati, and Louisville. Data from Table No. 105

the discrepancy between Pittsburgh and Cincinnati is reduced, but is still very great, the per capita pollution from Pittsburgh being from 15 to 27 per cent of that from Cincinnati according to the terms in which the bacteria are reckoned; that is, gelatin counts, agar counts, or *B. coli*.

It has long been known that the sewage from different cities varies considerably in volume and composition, so that the per capita discharge of organic matter, as indicated by determinations of nitrogen or oxygen consumed may be two or three times as great in some cities as in others; but the difference between Cincinnati and Louisville on

the one hand, and Pittsburgh and Wheeling on the other, with respect to the bacterial pollution contributed to the Ohio River are far beyond the range of the usual differences between cities in volume and composition of sewage. It would seem certain that the household wastes which constitute domestic sanitary sewage must be approximately the same in Pittsburgh and Wheeling as in Cincinnati or Louisville, so that these wastes from a given number of people must contain about the same amounts of organic matter and must be similar in original and potential bacterial content in all four cities. Differences in the other sewage components contributing to the organic constituents of combined sewage, namely, organic industrial wastes and surface wash, even though they may be considerable, can hardly within reason be supposed to account for a thirtyfold to one hundredfold difference in original bacterial content.

It would seem, therefore, that the observed differences in bacterial pollution contributed to the river from the Pittsburgh and Wheeling districts as compared with the Cincinnati and Louisville districts, can not reasonably be attributed to differences in the original character of organic wastes or their amounts per capita of population. The alternative explanation lies in a different direction or extent of the changes in bacterial flora between the original sources of the wastes and the sampling stations on the river below the respective cities. It may be:

(1) That a constant and considerable bacterial multiplication takes place in the Cincinnati and Louisville districts between the original sources of the wastes and the river sections where observations are made, but that this increase is inhibited in the Pittsburgh and Wheeling districts.

(2) That a constant and considerable bacterial decrease takes place between sources and sampling stations in the Pittsburgh and Wheeling districts, but to a less extent or not at all in the Cincinnati and Louisville districts.

(3) That changes in both directions take place in all four districts, but with a different balance between increase and decrease.

All things considered, it would seem that the ratios of bacterial pollution to population observed at Cincinnati and Louisville are the "normal" or usual ratios, comparable to what may be expected from other cities generally, and that the ratios are abnormally low at Pittsburgh and Wheeling, due to the action of unusual influences tending to destroy sewage bacteria or inhibit their normal multiplication. Certain it is, that, at least in the Pittsburgh district, some very unusual conditions exist which may reasonably be supposed to have this influence, namely:

(1) The waters of the Monongahela River show a high content of acid iron salts, and frequently the presence of free acid, due to the acid drainage from coal mines and wastes from steel industries.

These wastes apparently have a definite bactericidal and inhibitory effect. The waters of the Ohio, below the confluence of the Allegheny and Monongahela, though seldom reacting acid to methyl orange, have a high content of acid iron salts.

(2) When the waters of the Monongahela, carrying acid iron salts, meet the waters of the Allegheny, containing alkaline carbonates, a very noticeable precipitation results especially in the pool formed above Dam No. 1, when the wickets of the dam are raised. This would tend to hasten sedimentation, and might also tend to cause clumping of the bacteria enmeshed in the precipitate, thus reducing the bacterial plate count.

(3) During low river stages, such as prevailed from June to October, 1914, when the Ohio River dams below Pittsburgh are raised, the velocity of flow in this section of the Ohio, and in the Allegheny and Monongahela immediately above, is very low, so that the time elapsing between the discharge of sewage into the river from the sewer outlets of Pittsburgh and its arrival at sampling station No. 3 is quite prolonged. Since the sewer outlets are scattered, no exact calculation of time has been attempted; but the mean time of flow from the point of the Pittsburgh "peninsula" to station No. 3, as calculated for the months June to October, varied from 18 hours in June to more than 100 in October; and the mean time of flow from sewer outlets would probably be as great or greater. These are considerably longer than the estimated intervals between sewer outlets and proximal sampling stations at Cincinnati or Louisville; and it may well be supposed that the bacterial decrease taking place in the river in such time intervals is considerable (see p. 288). Such an explanation is not competent, however, to account for the low bacterial pollution from Pittsburgh during March, April, and May, for during these months high river stages prevailed, such that the calculated times of flow from the point of the "peninsula" to station No. 3 were less than 2.5 hours. According to all available evidence, the bacterial reduction resulting from the usual agencies of natural purification within such a short time interval, at winter temperatures, would be very slight.

Whatever its explanation, the extraordinarily low ratio of bacterial pollution to population in the Pittsburgh and Wheeling districts is a very remarkable, and, it would appear, a very fortunate fact. Had the pollution from the Pittsburgh metropolitan area borne the same ratio to population as at Cincinnati, the average agar count in the vicinity of Pittsburgh during the summer of 1914 would have been in the neighborhood of 1,000,000 per cubic centimeter, instead of the observed count of less than 30,000 per cubic centimeter.

Comparison with previous estimates of sewage bacteria per capita.—Taking a mean [17] between the estimate for Cincinnati (3 years) and

[17] A simple mean, giving the same weight to 1 year's observations at Louisville as to 3 years at Cincinnati.

that for Louisville (1 year), the average numbers of bacteria added to the river daily, per capita of sewered population are:

Gelatin count	11,300 billions.
Agar	10,100 billions.
B. coli	290 billions.

These numbers are considerably higher than the estimates commonly given. For example, Fuller[18] states that according to an estimate made by him in 1894, from observations at Lawrence, Mass., the sewage bacteria (presumably referring to gelatin count) amounted to about 320 billions per capita of sewered population per diem. Again, it is commonly stated that the bacterial count of sewage ranges from 1,000,000 to 10,000,000 per cubic centimeter, and that the number of *B. coli* is around 100,000 per cubic centimeter. Allowing a rather liberal per capita flow of sewage of 250 gallons per diem (for combined sewage), these figures would correspond to 946 billions and 9,460 billions, respectively, of total bacteria and 95 billions of *B. coli* per capita per day. These figures, again, are much in excess of those given by MacNeal, Latzer, and Kerr[19] for the average bacterial content of feces of normal men. They kept careful record for some months of the total weights of feces passed by some dozen men, and made frequent plate counts (on agar at 37° C.) of carefully prepared suspensions of weighed amounts. Their results showed that the average number of bacteria capable of development on agar at 37° C. was about 5 billions per capita per diem. Their figures are hardly comparable, however, to estimates based on the examination of sewage, since the bacteria in sewage are derived in part from sources other than human excreta, and since there is probably some multiplication in the sewers, or at least a disintegration of solid particles and clumps, tending to give a higher bacterial count.

INFLUENCE OF MAJOR TRIBUTARIES UPON THE POLLUTION OF THE OHIO RIVER

The monthly means of agar counts made at sampling stations upon tributaries which enter the Ohio River between Pittsburgh and Paducah are summarized in Table No. 106, together with the results of observations on the Ohio River at the station next above each tributary.

In addition to observations on these major tributaries, samples were collected from one to four times a month during June, July, August, September, and October, 1914, from the six large tributaries which empty into the Ohio between Wheeling and Portsmouth, namely, the Muskingum, Little Kanawha, Hocking, Kanawha, Guyandotte, and Big Sandy Rivers. The results of these examinations

[18] Fuller, George W., Sewage Disposal. McGraw-Hill Book Co., New York, 1912, 1st ed., p. 44.

[19] MacNeal, W. J., Latzer, L. L., and Kerr, J. F., The Fecal Bacteria of Healthy Men. Jour. Infect. Dis., 1909, vol. 6, Nos. 2 and 5.

are summarized in Table No. 107, to which are added corresponding results during the same months at Ohio River sampling stations Nos. 104 and 348, between which these tributaries empty into the Ohio.

TABLE NO. 106.—*Mean monthly numbers of bacteria (agar counts) at sampling stations on major tributaries of the Ohio River and at stations on main stream immediately above, 1914*

Sampling stations	Bacteria per cubic centimeter on agar at 37° C.											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Ohio River, 23	------	------	------	620	1,780	6,830	5,340	2,100	1,920	1,250	------	------
Beaver River	------	------	------	3,000	3,460	2,830	7,850	11,200	9,860	6,520	------	------
Ohio River, 348	816	993	630	1,060	904	440	1,290	1,720	816	836	------	------
Scioto River	2,130	4,140	3,060	3,500	1,810	2,850	3,000	11,400	3,140	7,840	------	------
Ohio River, 461	440	1,360	854	690	390	190	400	1,260	1,280	3,270	120	3,630
Little Miami River	640	5,060	3,260	2,970	926	5,500	3,180	11,800	2,620	3,800	1,140	12,400
Licking River	1,960	1,840	2,100	1,370	2,600	8,900	4,320	9,700	4,600	5,550	2,080	13,950
Ohio River, 488	------	------	------	4,940	24,900	50,800	29,900	29,800	50,800	27,900	79,300	45,400
Miami River	------	------	------	4,480	2,790	933	3,030	11,100	1,690	1,820	1,570	7,800
Ohio River, 543	------	------	------	------	------	------	------	2,860	8,900	3,800	3,150	13,200
Kentucky River	------	------	------	------	------	------	------	1,800	2,630	1,340	322	4,590
Ohio River, 904	------	------	------	------	924	646	129	221	811	414	------	------
Cumberland River	------	------	------	------	713	213	320	322	796	618	------	------
Ohio River, 920	------	------	------	------	639	690	200	225	684	479	------	------
Tennessee River	------	------	------	------	262	130	164	174	372	490	------	------

TABLE NO. 107.—*Mean monthly numbers of bacteria per cubic centimeter (agar count) at sampling stations on tributaries entering the Ohio River between Wheeling, W. Va., and Portsmouth, Ohio, June to October, 1914*

Sampling stations	Bacteria per cubic centimeter—Monthly means				
	June	July	August	September	October
Ohio River, No. 104	2,530	2,000	2,740	1,000	1,500
Muskingum River	----------	428	456	294	185
Little Kanawha River	----------	12,000	18,200	5,230	17,400
Hocking River	----------	370	1,150	677	330
Kanawha River	183	----------	328	177	147
Guyandotte River	563	354	11,300	2,460	136
Big Sandy River	722	43	499	500	73
Ohio River No. 348	438	1,290	1,720	816	836

According to these incomplete and generally unsatisfactory records, the Muskingum, Hocking, Kanawha, and Big Sandy showed but slight pollution, almost invariably less than that of the Ohio River at station 348. On the other hand, samples from the Little Kanawha at Parkersburg and from the Guyandotte at Huntington showed quite high pollution. It is probable, however, that these streams, at the sampling points chosen, were affected by local wastes from the adjacent cities, although it was thought, when the stations were located, that they were above all important local sources of pollution.

As to the tributaries included in Table No. 106, for which discharge estimates are available, their effect upon the pollution of the main stream at their respective junctions may be somewhat more

significantly stated. If the number of bacteria per cubic centimeter, as observed in the tributary, be converted into quantity units—that is, multiplied by the discharge in second-feet—and added to the bacteria carried by the main stream above, the sum represents the quantity units of bacteria carried by the main stream immediately below the tributary junction. Dividing this sum by the sum of the discharges of the main stream (above) and the tributary gives the number of bacteria per cubic centimeter in the main stream below the junction, which may be either greater or less than the number per cubic centimeter above the junction, according as the tributary is more or less highly polluted than the main stream. The difference (calculated number per cubic centimeter below junction minus observed number per cubic centimeter above) expressed as a percentage of the observed number per cubic centimeter above, indicates the percentage increase or decrease in the density (number per cubic centimeter) of bacteria in the main stream resulting from the inflow of the tributary. Table No. 108 shows the influence of six major tributaries as thus calculated for each month for which data are available, the calculations being based on agar counts as given in Table No. 106, with the addition of data for the years 1915 and 1916 for the Miami and Kentucky Rivers. The Little Miami and the Licking, which are included in Table No. 106, are omitted from this table because they join the Ohio River within the stretch which receives the sewage of the Cincinnati metropolitan district, and their effect upon the main stream is negligible in comparison to the effect of this sewage discharge. Also, it was unavoidable that the sampling stations on both these streams should be located below the outlets of certain sewers from the Cincinnati metropolitan district, so that the samples collected do not indicate precisely the conditions existing in the tributaries independent of this immediate pollution at their mouths.

TABLE No. 108.—*Influence of major tributaries upon bacterial count (numbers per cubic centimeter) of the Ohio River at their respective junctions as calculated from bacteriological examinations and discharge measurements of each tributary and of the Ohio River above its junction, based on agar counts, monthly means*

Month	Percentage increase (+) or decrease (−) in bacterial count (numbers per cubic centimeters) in main stream									
	Beaver River, 1914	Scioto River, 1914	Miami River			Kentucky River			Cumberland River, 1914	Tennessee River, 1914
			1914	1915	1916	1914	1915	1916		
January	--------	+8.4	--------	+8.2	+30.0	--------	−0.8	+0.3	--------	--------
February	--------	+29.0	--------	+36.5	+17.1	--------	−0.0	−1.2	--------	--------
March	--------	+48.0	--------	+2.2	+16.8	--------	+10.0	+.6	--------	--------
April	+48.0	−24.4	−0.5	−4.2	+.5	--------	−5.7	+2.6	--------	--------
May	+17.0	+6.4	−3.0	−4.6	−5.7	--------	−5.2	−.2	−2.5	−9.4
June	−4.8	+27.0	−5.4	+9.0	−3.6	--------	+6.2	+2.1	−6.0	−20.4
July	+3.7	+5.5	−4.5	−7.7	−2.9	--------	−1.3	+9.1	+30.2	−6.0
August	+38.0	+44.0	−4.8	−4.3	−1.9	−2.4	−.4	−2.1	+9.1	−7.6
September	+42.0	+14.0	−4.4	−8.1	−5.1	−5.3	−1.4	+13.9	−.6	−12.8
October	+52.0	−36.0	−6.4	−5.4	−2.6	−11.2	−1.9	+6.6	+5.8	+.6
November	--------	--------	−6.1	−4.1	−2.9	−2.3	−8.0	−1.6	--------	--------
December	--------	--------	−2.0	+5.4	−1.0	−4.8	+8.9	+.6	--------	--------

Of the six tributaries shown in this table only two, the Beaver and the Scioto, consistently tend to increase the pollution of the Ohio at their respective junctions. Both of these tributaries are at times fairly important factors in the total pollution of the main stream, increasing the density of bacteria from 25 to 50 per cent.

The influence of the Miami and Kentucky Rivers upon the pollution of the main stream is of interest because these are the only important tributaries which flow into the Ohio between Cincinnati and Louisville, in the stretch which is most favorable for the study of natural purification. The Miami, though it receives the sewage of two considerable cities, Dayton and Hamilton, within 85 miles above its mouth, is usually less highly polluted than the Ohio at their junction, which is about 20 miles below Cincinnati, and tends usually to decrease the pollution of the main stream. In 9 of the 33 months included in the tabulation the effect was in the opposite direction and in 4 of these months during the winter season was over 15 per cent. With these four exceptions the effect, in either direction, was less than 10 per cent; that is, within the margin of probable observational error.

The Kentucky River joins the Ohio midway between Cincinnati and Louisville, at a point where the Ohio is less highly polluted than at the Miami junction and consequently more sensitive to added pollution. Notwithstanding this the influence of the Kentucky was more frequently to decrease than to increase the bacterial count in the Ohio. In only three months did the effect in either direction exceed 9 per cent.

The Cumberland and the Tennessee are the two largest tributaries of the Ohio, both joining the main stream within the last 50 miles of its course. The Cumberland River in one month added materially (30 per cent) to the pollution of the Ohio, but in the remaining five made no material change. The Tennessee was found to be somewhat less polluted than the Ohio River at their junction. However, the Ohio, at its junctions with these rivers, was very slightly polluted during the period of observation, and both the Cumberland and the Tennessee were found to be much less polluted than any of the other major tributaries included in Table No. 106.

In general, none of the major tributaries of the Ohio appears to make any abrupt change in the status of pollution of the main stream, and, as a rule, though with exceptions, the tributaries at their mouths are less highly polluted than the Ohio, as would be expected in view of the greater concentration of urban population along the course of the main stream.

CHANGES IN BACTERIAL CONTENT OF THE RIVER BETWEEN SUCCESSIVE SAMPLING STATIONS

In passing downstream from Pittsburgh the bacterial content of the river is constantly changing, due to the inflow of sewage from cities, tending to increase the pollution; the inflow of tributaries,

tending either to increase or decrease it, and the action of natural agencies, presumably both physical and biological, tending generally toward the destruction or removal of bacteria. These changes, as indicated by gelatin counts, agar counts, and *B. coli* index, are shown in detail for each month in the basic tables already presented, but a better general view of them is given by Table No. 109, in which the agar counts at all sampling stations on the Ohio are shown in the form of means for four periods of 1914, namely: (1) January to March, (2) April, (3) May, and (4) June to October. As shown in the following summary, each of these periods represents a different range or combination of temperature and discharge, the physical conditions which are apparently of most influence in determining the bacterial content of the river.

1914	Discharge at Cincinnati, second-feet			River temperatures at Cincinnati, °C		
	Maximum [1]	Minimum [1]	Mean	Maximum [1]	Minimum [1]	Mean
January to March	248, 000	64, 200	144, 000	9. 2	0. 5	2. 7
April	364, 000	171, 000	248, 000	15. 7	7. 5	10. 5
May	202, 000	27, 800	126, 000	22. 5	15. 5	17. 1
June to October	49, 300	6, 970	16, 200	30. 5	18. 5	24. 6

[1] Maxima and minima refer to daily observations.

TABLE No. 109.—*Summary of average bacterial counts (agar) at principal Ohio River sampling stations during four seasonal periods of 1914*

Ohio River sampling stations	Mean numbers of bacteria per cubic centimeter			
	Jan. 1–Mar. 1 (mean temperature 2.7° C., mean discharge 144,000 sec.-ft.)[1]	April (mean temperature 10.5° C., mean discharge 248,000 sec.-ft.)[1]	May (mean temperature 17.1° C., mean discharge 126,000 sec.-ft.)[1]	June 1 to Oct. 15 (mean temperature 24.6° C., mean discharge 16,200 sec.-ft.)[1]
3	800	[2] 900	2, 440	27, 000
11	280	600	1, 280	4, 000
19		500	1, 100	2, 090
23		620	1, 780	3, 490
29		934	3, 340	
65			519	758
77			565	1, 260
88			447	704
97			627	2, 970
104			414	1, 950
348	813	1, 060	904	1, 020
358	1, 190	1, 310	895	1, 420
461	885	690	390	900
475	2, 793	4, 350	28, 000	233, 000
482	1, 627	5, 000	20, 200	67, 700
488		4, 940	24, 900	34, 400
492		7, 440	39, 500	31, 800
543				4, 100
598	3, 470	3, 250	2, 780	573
611	3, 950	2, 860	3, 890	40, 800
619	3, 330	2, 880	5, 600	55, 400
904			924	444
920			639	456
933			809	431

[1] Mean temperatures and discharges as observed at Cincinnati, station 475.
[2] Mean for station No. 5, 2 miles below station No. 3, the observations at the latter station having been interrupted.

During the first period, from January to March, characterized by moderately high river stages and low temperature, the bacterial count is not very high at any point, the maximum being 3,950 per cubic centimeter at station 611, below Louisville. The large cities, Cincinnati and Louisville, increase the pollution perceptibly but not greatly. The decrease (about 30 per cent) in the long stretch 348–461 is of doubtful significance; and in the stretch between Cincinnati and Louisville (475–598) there is an actual, though hardly significant, increase. On the whole, the pollution tends to increase from Pittsburgh to Louisville.

During April the ranges of pollution are similar; but there is a definite and considerable decrease in bacterial counts in the two long stretches, 348–461 and 475–598, which are relatively free from additions of sewage.

In May the bacterial count immediately below each of the large cities is higher than in the preceding periods, notably so below Cincinnati, and a very marked reduction takes place in stretches 3–11, 23–65, 358–461, 475 (or 492)–598, and 619–904. In the short stretches 475–492 and 611–619, immediately below Cincinnati and Louisville, respectively, the bacterial counts are increased, not decreased, as might have been expected. As the differences between this period and the winter period (January to March) in discharge, and consequently in times of flow between successive points, are not very considerable, the greatly altered range and course of bacterial pollution would appear to be related to the difference in temperature. The effect of a higher temperature might be either direct, favoring the multiplication of bacteria in sewage and accelerating their death rate in the river, or indirect, through the establishment of a different biological balance between bacteria and plankton.

The period from June to October represents fairly stable conditions of summer temperature, from 18° to 26° C., low water, and greatly prolonged times of flow from section to section. The bacterial counts immediately below the large cities are increased very greatly, especially below Cincinnati and Louisville, reaching an average of 233,000 per cubic centimeter at station 475; but this is counterbalanced by the much more extensive bacterial decrease in stretches below these and the other cities, so that at stations 65, 348, 461, 598, and 904, which are fairly remote from sources of gross sewage pollution, the counts are hardly any greater, or in some instances are less, than during the winter and spring periods. The most extensive purification takes place in the stretch from 475 to 598, within which the bacterial count decreases from 233,000 to 570 per cubic centimeter, a reduction of 99.75 per cent.

The extreme differences between winter and summer conditions, with respect to time intervals between successive stations, as well as

range of bacterial pollution, may be appreciated more readily from a graphic representation, as in figure No. 30, in which observations for two typical months, January and September, are plotted upon a uniform scale.

PART II

THE EXTENT AND RATES OF NATURAL PURIFICATION

It is sufficiently evident from the facts already shown that extremely potent forces are operative, especially during the summer, tending toward the removal or destruction of the bacteria added in the sewage from urban communities, and that their net effect in reducing the bacterial content of the river at points remote from the major sources of pollution is enormous. To give a single illustration, if the bacteria present in the Ohio River at station No. 3, below Pittsburgh, plus those added at Wheeling, Cincinnati, and Louisville had all remained in the river, and alive, the bacteria from these sources alone would have given a mean count of 91,000 per cubic centimeter below Paducah (at station 933), during the months from June to October, 1914, instead of the observed count of 431 per cubic centimeter.

But while it is a very simple matter to demonstrate the fact that the bacteria in many stretches of the river are undergoing a rapid decrease due to natural agencies other than mere physical dilution, it is not so simple to measure the reduction directly attributable to these agencies. This requires that other factors influencing the numbers or density of the bacteria be excluded or accounted for; and there are few stretches of the river in which these conditions can be met. For example, between stations 3 and 11, below Pittsburgh, the river receives additional pollution from the sewage of about 35,000 people. Between stations 23 and 65 it receives the inflow of the Beaver River, as well as the sewage from 48,000 sewered population, while between stations 104 and 348, also between stations 619 and 904, a number of cities discharge sewage and several major tributaries join the Ohio. Therefore while it is evident from the observations made that purification is proceeding actively in these stretches, its effects are to some extent masked. The stretch immediately below Louisville, between stations 611 and 619, though free from any additional sewage pollution of measurable effect and from any significant inflow from minor tributaries, does not serve to measure natural purification, because the tendency between these stations is usually toward an increase rather than a decrease in pollution, and because it seems probable that the observations at station 611 are affected by a sampling error of such magnitude as to make them unreliable.

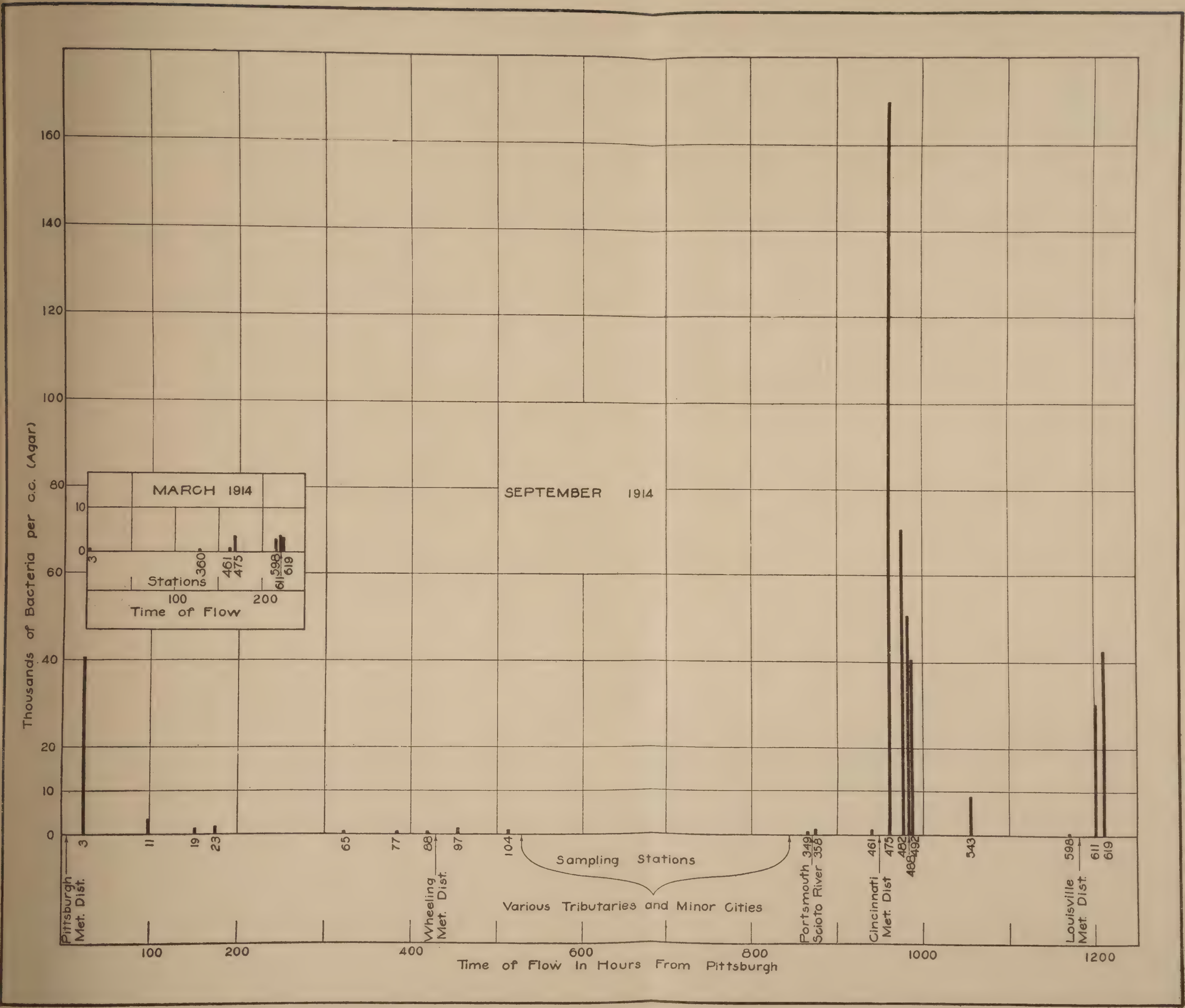

FIG. 30.—Agar counts at successive sampling stations on the Ohio River in relation to time of flow in March and in September, 1914

95404°—24. (Face p. 262.)

RIVER STRETCHES SUITABLE FOR STUDY OF NATURAL PURIFICATION.

This leaves only two long stretches, 348–461 and 475–598, which are sufficiently free from increments of sewage pollution and of discharge to be considered suitable for quantitative study of natural purification.

The first of these stretches extends from station 348, just below the junction of the Scioto River, to station 461, a short distance above Cincinnati. No major tributaries join the Ohio between these sections, and the minor tributaries which discharge into it have a combined drainage area of not more than some 2,200 square miles, which is but little over 3 per cent of the drainage area above station 348, and may be considered, therefore, as making no material increase in the discharge. The total population of towns and villages situated along the shores is about 6,000, including less than 3,000 served by sewerage systems, distributed as shown in Figure 14, p. 69; and it is certain that the sewage from such a small population would have hardly any measurable effect upon the pollution of the Ohio. The monthly mean times of flow from station 348 to 461 varied, during the 10 months of observation, from 34 to 100 hours; and the general tendency, as shown by reference to Table No. 109, was toward a decrease in numbers of bacteria between the upper and lower stations.

This stretch would appear, therefore, to be suitable for a quantitative study of natural purification; but analysis of the observations at stations 358 and 461 shows that the bacterial decrease between these sections was not consistent in all months, even during the period from June to October, and was not at all comparable in extent to the decrease taking place in similar time intervals between Cincinnati and Louisville (stations 475 to 598). Since the interpretation of these rather puzzling observations, so far as they can be interpreted at all, is dependent largely upon inferences derived from a study of the stretch from stations 475 to 598, it will be more profitable to consider the latter stretch first, returning later to this one.

The river stretch between Cincinnati and Louisville.—The upper sampling station in this stretch, station 475, was located 6 miles above Dam No. 37, about 7 miles below the central portion and main sewer outlets of Cincinnati, and well below the outfalls of all large sewers from this district. The lower station, No. 598, was located just above Louisville, opposite the intake of the municipal waterworks. Between these sections were four other sampling stations, Nos. 482, 488, 492, and 543. As the numbers of these stations correspond to their respective distances in miles from Pittsburgh, the distance between any two of them is indicated by the difference between their designating numbers. The location of each of these stations is described more minutely in Section IV, pp. 98–104, and

their relations to tributary outlets and villages are shown in Figure No. 14, Section III.

Within this stretch the Ohio receives two important tributaries, the Miami, entering between stations 488 and 492; and the Kentucky, entering just below station 543. These two rivers together drain an area of about 12,320 square miles; and minor tributaries add a drainage area of about 1,800 square miles. Altogether, then, the drainage area above the Miami, which is 76,586 square miles, is increased by about 19 per cent at station 598; and this is approximately the ratio of increase in discharge, although this varies from month to month.

The aggregate population of all the villages situated immediately adjacent to the river within the stretch was, in 1915, about 15,100, but the sewered population amounted to only about 1,700, distributed in small groups, none being of sufficient size to add measurably to the bacterial content of such a large stream as the Ohio, even at low stages.

Observations at stations 475, 482, and 598 extended through three full calendar years, 1914, 1915, and 1916; at stations 488, 492, and on the Miami, extended through 33 months, from April, 1914, to December, 1916, inclusive; and at stations 543 and on the Kentucky they covered 29 months, from August, 1914, to December, 1916, inclusive. Sampling schedules, which varied somewhat from time to time, are shown in detail in Figures 21 and 22, Section IV. For the most part, collections were made six times weekly from stations 475, 482, and 598; three to six times weekly from stations 488, 492, and the Miami River; and twice weekly from stations 543 and the Kentucky River.

Influence of tributaries between Cincinnati and Louisville.—As gaging stations were maintained on the Miami and Kentucky Rivers, and records kept of daily gage heights, the discharges from these streams can be calculated with fair precision; and these discharge figures, when combined with bacteriological observations on each tributary and on the main stream immediately above, furnish the data required for determining the influence of the tributary upon the bacterial content of the Ohio at the junction point.

An analysis from this point of view, showing the influence of each of these tributaries upon the density of bacteria in the Ohio at their respective junctions, by months, has already been presented in Table No. 108, p. 258.

During the months April to November, 1914, 1915, and 1916, the inflow of the Miami, as calculated in this table, affected the bacterial count as observed at station 488 by less than 10 per cent, usually less than 5 per cent; and in 22 of these 24 months the tendency of this effect was toward a decrease in the pollution of the Ohio. Dur-

ing the winter months, December to March, the influence of the Miami was usually in the other direction, tending to increase the pollution of the Ohio, and was relatively greater. The maximum effect observed was an increase of 36.5 per cent in one month; and in three other months the effect ranged between 15 and 30 per cent, but even in winter the effect was usually under 10 per cent.

The effect of the Kentucky was likewise more frequently to decrease the pollution of the Ohio during the summer months and to increase it during the winter; but, with two exceptions, the calculated effect in either direction was less than 10 per cent, the maximum influence being an indicated increase of 14 per cent in one month.

Whether or not the attempt be made to correct observations at station 598 to take account of the influence of these tributaries, certain assumptions are necessary in either case. Correction may be made by adjusting the bacterial count observed in the main stream above the tributary junction to the count that would result immediately below the junction from mixture of the two streams. This involves two assumptions, namely:

(1) That aside from the influence of the tributary, the numbers of bacteria in the main stream would undergo no change between the sampling station above the tributary and a point corresponding to the junction. Such an assumption would perhaps be warranted at the junction of the Kentucky; but in the zone of the Miami junction the bacterial content of the Ohio is usually changing at a very rapid rate, so that even in the short distance between stations 488 and 492 (where the correction would have to be applied) this assumption would be more or less in error.

(2) That the bacteria added from the tributary, after they had reached the main stream, followed the same course of changes, and at the same rate as the bacteria originally present in the main stream. This need not necessarily be the case, but no other assumption is justified or workable.

If no correction is attempted, the effect of tributary inflow being disregarded, this also implies two assumptions, namely:

(1) That the density of bacteria in the tributary was the same as that in the main stream at the junction.

(2) The second assumption stated above as to identical rates of decrease below the tributary junction.

As a matter of fact it makes no very great difference whether "corrections" for tributary inflow be made or not, for, as indicated by Table 108, neither the Miami nor the Kentucky makes any very material change in the state of pollution of the Ohio at their respective junction points except under rather rare conditions; and ordinarily any correction attempted would be within the range of observa-

tional error. Therefore, the simpler method has been followed, of attempting no corrections for these tributaries, this being the method which must necessarily be applied to the minor tributaries for which no data are available.

In certain of the analyses which follow, results are expressed in "quantity units" (bacteria per cubic centimeter multiplied by discharge in thousands of second-feet); and in such cases the discharge factor used at all stations, including station 598, is the discharge observed at station 475. This is equivalent, in the assumptions which it implies, to the method followed in dealing with numbers per cubic centimeter, where no correction for tributary inflow is attempted.

On the whole, it appears from a careful study of all the data that the inflow from the Miami and Kentucky Rivers ordinarily introduces no material error in observations between stations 475 and 598; and the same is probably true, in general, in the minor tributaries. Under certain conditions, however, when the Ohio is at low stages and bacterial content in the lower half of the stretch below the Kentucky River is very low, the inflow from small tributaries, swollen by local rains, may temporarily increase the bacterial count at station 598 to a disproportionate extent, thus tending to obscure partially the effects of natural purification. It is doubtful that the tributary inflow ever tends materially to exaggerate the apparent reduction attributable to natural purification.

METHODS OF GROUPING DATA FOR STUDY OF NATURAL PURIFICATION.

Since the tendencies shown by the gelatin counts, the agar counts, and the *B. coli* group are substantially the same, it is unnecessary to discuss them all in detail; and the agar count group, which seems to be more or less intermediate between the gelatin count and *B. coli* groups, will be taken as a basis for discussion, giving parallel tabulations of gelatin counts and *B. coli* determinations only as may be necessary for final comparisons.

Seasonal periods.—It will also be convenient, from the outset, to group the data in two seasonal periods, a "winter" period, including the months December, January, February, and March; and a "summer" period, comprising the months April to November, inclusive, since the bacteriological phenomena in these two periods differ distinctly.

The winter period represents temperature conditions quite distinct from those of other months, and of quite narrow range, since the monthly mean temperatures of the river water in these months vary only from 1.5° to 4.7° C. The range of mean discharges in these months is from 64,000 to 304,000 second-feet, that is, it includes high and moderate discharges, but not the low rates frequently observed in summer

The temperature range during the months from April to November is quite wide, the monthly means varying from 8° to 27° C. Any detailed study of the relation of temperature to the rate of natural purification would therefore require a subdivision into narrower temperature ranges, and with this purpose in view these eight months were originally grouped as follows: April and November, temperatures 8° to 12.5° C.; May to October, temperatures 15° to 19° C.; and June to September, inclusive, temperatures 21° to 27° C. However, a number of preliminary analyses of data classified in this manner and in other seasonal groupings have failed to show any consistent differences in the bacteriological phenomena which can be related to temperature or other seasonal changes within the range represented by the months from April to November; and it has seemed preferable to consider these eight months as a single seasonal period rather than to attempt any more elaborate classification.

The observations within this seasonal period include altogether 24 months (8 months each year for three years), covering a wide range of stream flow conditions, with monthly mean discharges varying from 11,800 to 248,000 second-feet. During 16 of these months the discharges were less than 60,000 second-feet, thus falling below the minimum observed in any month of the winter period; but during the other 8 months the discharges, ranging from 70,000 to 248,000 second-feet, were within the same range as those observed in the winter. It is thus possible, in the months when discharge conditions were comparable to those obtaining in winter, to distinguish differences in bacteriological phenonema not attributable to differences in stream flow, velocity, and time intervals.

The bacteriological phenomena of the winter season differ from those of the warmer months not only in rates of purification, which are discussed later; but also in higher ratios of gelatin counts to agar counts and to *B. coli*, and, in the zone immediately below Cincinnati, in much lower bacterial counts in proportion to discharge. For example, in June, 1916, with a discharge of 109,000 second-feet the agar count at station 475 was 27,200, whereas in January, 1914, with a discharge of 88,700 second-feet, the count was only 3,080 per cubic centimeter. A study of daily observations shows that the change in bacteriological conditions was established each year in late November, or early in December, with surprising suddenness. The change from winter to "summer" conditions was more gradual and more variable in time, but was more or less definitely established during the month of April in each of the three years of study.

95404°—24†——19

SUMMARY OF MONTHLY MEAN COUNTS BETWEEN CINCINNATI AND LOUISVILLE

The monthly mean agar counts at all sampling stations between Cincinnati and Louisville during these two seasonal periods of 1914, 1915, and 1916, are summarized in Table No. 110, which also shows for each month; the mean river temperature, gage height at Cincinnati (lower gage, Dam No. 37), discharge at Cincinnati, and the mean time of flow to each station from the middle of the river prism, 461–475, in which Cincinnati lies. This section, at a distance of 7 miles above station 475, corresponds approximately to the center of the Cincinnati metropolitan district, near the junction of Mill Creek, and is in the vicinity of the main sewer outfalls. It is taken as representing the sewer outfalls of the entire metropolitan district. Actually, these outfalls are distributed along the whole water front, over a distance of about 15 miles, but this section represents approximately their mean distance above station 475, and the approximate distance of the larger sewer outlets. The months in each seasonal period are arranged in this table in ascending order of discharge, which corresponds to descending order in relation to time of flow from the origin to any station.

Table No. 110.—*Monthly mean river temperature, river stage, and discharge at Cincinnati, time of flow from Cincinnati sewer outlets to designated stations and mean numbers of bacteria per cubic centimeter (agar counts)*

APRIL TO NOVEMBER, 1914; 1915 AND 1916

Months	River temperature at station 475	River stage dam No. 37	Discharge M. sec.-ft. at station 475	Time of flow (hours) from sewer outlets and numbers of bacteria per cubic centimeter at each station											
				475		482		488		492		543		598	
				Time	Bacteria	Time	Bacteria	Time	Bacteria	Time	Bacteria	Time	Bacteria	Time	Bacteria
November, 1914	8.3	2.8	11.8	12.9	*198,000	32.8	67,700	40.6	79,300	44.6	85,100	136.2	3,150	295.2	124
August, 1914	26.3	3.7	15.2	11.8	*262,000	28.3	41,100	35.3	29,800	38.8	39,600	117.7	2,860	246.9	1,250
October, 1914	17.8	3.7	16.9	11.2	*203,000	28.0	48,900	35.0	27,900	38.6	24,500	117.2	3,800	245.2	700
September, 1914	22.6	4.4	17.5	10.1	*170,000	24.8	70,700	31.3	50,800	34.8	40,600	105.6	8,900	220.1	506
November, 1916	9.3	4.7	18.2	9.5	102,200	23.4	*118,700	29.7	118,000	33.0	115,500	100.7	18,100	208.7	800
September, 1916	22.2	4.8	18.7	9.3	*151,900	22.8	142,200	29.1	49,000	32.3	39,600	99.0	11,200	205.8	800
July, 1914	27.3	4.9	19.0	9.3	*147,000	22.8	82,700	29.0	29,900	32.3	23,900	101.0	([1])	206.4	203
June, 1914	26.2	5.3	21.0	8.0	*237,000	19.6	91,800	25.5	50,800	28.7	48,900	89.7	([1])	174.0	586
October, 1916	15.6	5.6	24.2	7.8	*216,100	18.5	98,100	24.3	54,100	27.4	49,000	77.4	8,100	173.2	800
April, 1915	12.4	9.6	41.6	4.6	64,100	10.8	53,300	14.9	*78,400	17.3	67,700	55.2	10,300	117.1	220
August, 1916	26.1	9.8	45.6	4.6	74,200	10.6	*97,350	14.6	83,500	17.0	72,800	54.0	20,400	114.4	5,100
July, 1916	26.3	10.1	47.2	4.4	*86,700	10.3	63,600	14.2	60,000	16.5	55,900	52.5	31,100	111.6	4,100
September, 1915	22.5	10.3	52.1	4.3	*60,300	10.0	56,700	13.8	54,900	16.1	44,600	51.3	([2])	109.2	2,880
November, 1915	10.4	11.0	58.6	4.2	72,700	9.6	*88,700	13.2	61,100	15.4	53,500	48.4	27,000	102.5	3,360
May, 1915	18.8	11.3	56.0	4.0	54,700	9.2	54,100	12.8	*58,400	15.0	47,500	47.2	32,000	99.7	3,450
August, 1915	24.1	11.6	54.8	4.0	51,900	9.1	35,400	12.6	54,500	14.8	*64,200	46.2	47,700	97.2	2,810
October, 1915	16.6	13.0	70.4	3.7	39,200	8.3	*70,900	11.7	69,600	13.7	43,400	42.1	13,900	87.1	3,070
June, 1915	22.3	13.9	74.8	3.5	27,800	7.8	24,900	10.9	*35,900	12.8	34,400	39.8	15,000	81.0	3,220
July, 1915	24.9	14.2	75.2	3.4	*57,300	7.6	37,700	10.7	42,200	12.6	39,800	39.3	([2])	79.1	4,500
May, 1916	17.7	16.9	96.8	3.0	27,500	6.6	30,400	9.4	37,200	11.1	*37,600	34.8	18,400	67.0	2,800
June, 1916	21.0	18.4	109.0	2.8	27,200	6.2	20,100	8.7	28,200	10.4	*32,600	32.7	19,400	61.5	4,800
May, 1914	17.1	19.9	126.0	2.7	28,000	5.9	20,200	8.3	24,900	9.8	*39,500	31.0	([1])	57.4	2,780
April, 1916	9.9	28.5	207.0	2.2	4,600	4.9	5,200	7.0	5,280	8.3	*5,800	25.6	4,800	44.8	2,000
April, 1914	10.5	32.7	248.0	2.1	4,350	4.6	5,000	6.5	4,940	7.8	*7,440	23.9	([1])	41.7	3,250

[1] No samples collected

[2] The results at this station in July, 1915 (58,900 per cubic centimeter), and September, 1915 (82,900), are omitted because they are based on few observations and are believed to be in error, due possibly to bacterial multiplication during transportation of samples.

*Indicates maximum count

TABLE NO. 110.—*Monthly mean river temperature, river stage, and discharge at Cincinnati, time of flow from Cincinnati, sewer outlets to designated stations and mean numbers of bacteria per cubic centimeter (agar counts)*—Continued

WINTER MONTHS, DECEMBER JANUARY, FEBRUARY, MARCH, 1914, 1915, 1916

Months	River temperature at station 475	River stage dam	Discharge M.sec.-ft. at station 475	Time of flow (hours) from sewer outlets and numbers of bacteria per cubic centimeter at each station											
				475		482		488		492		543		598	
				Time	Bacteria	Time	Bacteria	Time	Bacteria	Time	Bacteria	Time	Bacteria	Time	Bacteria
December, 1916	4.0	12.1	63.6	3.8	*12,300	8.7	8,640	12.1	9,680	14.2	10,800	44.7	6,200	93.7	4,500
December, 1914	4.7	15.2	88.2	3.2	25,700	7.2	14,800	10.1	*45,400	11.9	37,400	37.3	13,200	76.3	2,400
March, 1915	4.5	15.4	84.2	3.2	*2,480	7.1	1,160	10.0	1,470	11.8	2,010	36.9	1,370	73.1	543
January, 1914	2.1	17.3	99.7	3.0	3,080	6.6	1,560	9.3	----------	11.0	----------	34.0	----------	66.2	2,730
December, 1915	3.1	21.4	149.0	2.6	*5,930	5.7	4,220	8.5	4,180	10.0	4,870	30.3	4,030	54.3	4,870
March, 1914	3.3	24.0	160.0	2.5	3,480	5.5	1,570	7.7	----------	9.1	----------	27.5	----------	49.7	2,780
February 1914	2.8	25.3	173.0	2.4	1,820	5.2	1,750	7.4	----------	8.8	----------	27.8	----------	50.7	4,900
January, 1915	1.5	26.2	183.8	2.3	3,120	5.1	2,640	7.2	2,630	8.6	*3,820	26.8	2,280	46.8	2,780
March, 1916	4.5	28.4	205.0	2.2	4,000	4.9	3,700	7.0	3,600	8.3	*4,400	25.7	3,400	44.9	4,000
February, 1916	3.8	30.3	220.0	2.2	3,300	4.9	2,900	6.8	2,850	8.2	3,300	24.9	3,600	43.5	*4,200
February, 1915	3.3	31.9	245.1	2.2	1,820	4.7	1,550	6.6	1,250	7.9	2,040	24.2	*2,360	42.2	2,240
January, 1916	3.7	37.8	304.0	2.1	3,800	4.1	3,900	5.9	3,620	7.2	4,800	22.2	*6,500	38.6	4,800

* Indicates maximum count.

Occurrence of maximum count below Cincinnati.—Referring first to the observations for the months from April to November, it is seen that there is invariably a decrease in the numbers of bacteria between station 475, next below Cincinnati, and station 598, at the extreme lower end of the stretch; and that this decrease is greater as the time of passage between these stations increases. Beyond this it may be noted:

(1) That in certain months this decrease is consistent and progressive, the count being highest at station 475 and decreasing regularly at each successive downstream station.

(2) That in certain other months there is a regular increase in counts at successive downstream stations, until a maximum count is reached at station 482, 488, or 492; and from that point downstream a progressive decrease.

(3) That in still other months there are irregularities in the sequence, as for instance in the first month (November, 1914), shown in the table, where a marked decrease from station 475 to station 482 is followed by higher counts at stations 488 and 492.

Irregular as these results appear at first inspection, there is nevertheless a certain regularity in their tendencies. In the first 12 months, that is at river stages of 10.1 feet or less, the highest count was observed:

At station 475, 9 times;
At station 482, twice;
At station 488, once.

In the second 12 months, at river stages of 10.3 feet or over, the highest count was observed:

At station 475, twice;
At station 482, twice;
At station 488, twice;
At station 492, 6 times.

Thus, the maximum count tends to occur farther downstream as the river stage rises; that is, as velocity of flow increases, and as the time elapsing from the sewer outlets of Cincinnati is shortened.

Counting each monthly mean as one observation, the table shows a total of 96 observations during this period, at stations 475, 482, 488, and 492, at time intervals from sewer outfalls varying from two to 45 hours. The 24 maximum counts, one in each month, occurred, in different months, sometimes at one, sometimes at another of these stations, at time intervals ranging from 3.5 to 24 hours.[20] The

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[20] As actually recorded, the maximum count occurred twice at station 543; in July, 1915 (time 39 hours), and in September, 1915 (time 51 hours), but as the figures for these months are largely determined by a few excessively high counts, which may have been attributable to multiplication of bacteria in transportation to the laboratory, they are omitted from Table No. 110. In general, the observations at station 543 are less reliable than those at other stations, because samples were collected less frequently and shipped in by express, subject to a delay of four to eight hours in reaching the laboratory.

distributions, by time, of the 96 observations and of the 24 maximum counts, are shown in Table No. 111, from which it is seen that the maximum count occurred most frequently in time intervals from 8 to 14 hours.

TABLE NO. 111.—*Distribution of observations and of occurrence of maximum agar counts at stations 475, 482, 488, and 492, in time intervals from sewer outfalls of Cincinnati*

Time intervals from sewer outfalls	Frequency: All observations at stations 475, 482, 488, and 492	Frequency: Occurrence of maximum	Time intervals from sewer outfalls	Frequency: All observations at stations 475, 482, 488, and 492	Frequency: Occurrence of maximum
Under 2 hours	0	0	18–20 hours	2	0
2–4 hours	8	1	20–22 hours	0	0
4–6 hours	10	2	22–24 hours	3	1
6–8 hours	7	1			
8–10 hours	13	8	Total under 24 hours	74	24
10–12 hours	13	7	24–46 hours	22	0
12–14 hours	8	2			
14–16 hours	6	2	Total	96	24
16–18 hours	4	0			

Referring to the above table, the maximum count occurred in time intervals of:

Less than 8 hours, 4 times in 25 observations, or 1 in 6.25.

From 8 to 12 hours, 15 times in 26 observations, or 1 in 1.7.

From 12 to 16 hours, 4 times in 14 observations, or 1 in 3.5.

From 16 to 24 hours, once in 9 observations.

More than 24 hours, not at all in 22 observations.

This indicates that while the highest bacterial count occurs quite irregularly with respect to distance from the sewer outlets, it nevertheless does tend, with some degree of consistency, to occur within rather definite limits of time from the sources of pollution. The inference which this suggests, that the sewage bacteria increase in numbers during the first few hours after their discharge into the river, seems at first thought to be most unlikely; but it may be noted that such an increase need not necessarily be attributed to actual multiplication of cells. It might be due merely to the disintegration of clumps of bacteria, which, when clumped, would give only one plate colony each and so would be counted as single cells. It is, indeed, quite probable that the actual numbers of living bacteria as found in fairly fresh sewage are quite considerably in excess of the numbers indicated by plate counts, due to such clumping of cells, and their inclusion in or adherence to solid particles. It need not be altogether surprising, therefore, if the plate count does increase in a stream for some hours after sewage has been mixed with it; and a net increase is not entirely inconsistent with the view that the bacteria may be

actually dying during this same period at a fairly rapid rate but not rapidly enough to counterbalance the increase in plate counts due to liberation of individual cells from clumps.

But, while the above facts certainly suggest that the number of free and living bacterial cells originally added in the sewage tends for some hours to increase in the river, either by disintegration of clumps or by actual cell multiplication, this is not a necessary conclusion, since there is at least a possibility, perhaps a reasonable probability, that the apparent increase may be due wholly to sampling errors.

Sampling errors due to imperfect mixture of sewage in river below Cincinnati.—It has already been explained (p. 94, Section IV) that at each sampling station samples were taken from three points on a cross section, these points being so located that at ordinary river stages each would be in the center of one-third of the cross-sectional

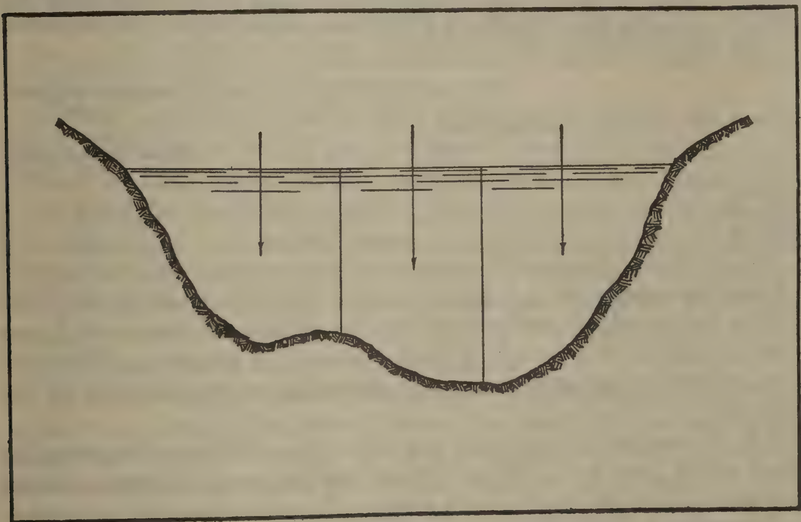

FIG. 31.—Diagrammatic illustration of location of three sampling points on a river section

area. To locate these points the cross section, after being plotted, was first divided vertically into three equal areas; then each of these was again divided by a vertical line into two equal areas; and the sampling points located at mid depth on these three lines, as illustrated in the accompanying diagram. The samples from these three points were examined separately, and their mean taken as representing the cross section.

Sewage from the Cincinnati metropolitan district comes into the river chiefly from the north, or Cincinnati side, comparatively little being discharged from the south, or Kentucky side; and it is presumably carried downstream in a "thread" or "streak" which at first is quite narrow, hugging the shore, but gradually extends across the stream as the sewage becomes more thoroughly mixed with the river water. The vertical mixture seems to be fairly uniform by the time

the river reaches station 475, even in pool stages of the river; for on a number of occasions samples taken near the surface, at mid depth, and near the bottom were compared as to bacteriological content and showed no consistent differences.

The progress of lateral mixture may be followed roughly by comparing the observations at the three sampling points at each of the four sections represented by sampling stations 475, 482, 488, and 492; and, for the purpose of this comparison, the agar counts made in the 24 months, April to November, inclusive, for the years 1914, 1915, and 1916, have been compiled to show the mean count at each sampling point on each of the four sections for the whole period of 24 months. The mean at each of the three points on each cross section has then been reduced to a percentage of the mean for the cross section, as shown in Table No. 112, following:

Table No. 112.—*Percentage which the agar count at each point on each of the four sections, 475, 482, 488, and 492, is of the mean for that section—Means for the period April–November, 1914, 1915, 1916*

Sampling station	Percentage of section average		
	North point	Center point	South point
Station 475	205	67	38
Station 482	172	84	44
Station 488	137	105	58
Station 492	117	117	66

From this summary it is seen that the mixture of sewage with the river is by no means uniform across the section at station 475, nor even at station 492; but that from station 475 to station 492 there is an orderly, progressive tendency toward greater uniformity of the mixture.

It is useless to attempt any quantitative analysis of the sampling errors which may result from the varying stages of mixture at these four sampling stations, for such analysis becomes possible only when the conditions are greatly simplified by assuming some definite, constant and relatively simple course of progressive diffusion across the stream. Obviously no such simple conditions can be supposed actually to obtain in the Ohio River, since its course is tortuous, while the bottom contour is constantly changing. In consequence there must be numerous and complex currents in all planes, doubtless varying with changes in river stage and velocity, so that the course of mixture between the river water and the sewage from Cincinnati must be quite complex and variable. It may, however, be inferred, from the data shown in Table No. 112, that the progress of mixture is more or less regular, at least to the extent that the densities of bacteria at various points on a cross section decrease progressively from the proximal to the distal side; and even this general condition warrants some inferences as to the direction, if not the magnitude, of sampling errors.

To consider first the proximal third of the cross-sectional area, with the proximal sampling station located on its mid line; the sample from this point correctly represents the area only when it shows a density of bacteria which is the mean of the varying densities at all points in the area; but in a certain stage of the outward diffusion of sewage a sample from this point must necessarily show a density of bacteria less than the true mean for the area. For example, in the first stage, when the sewage is concentrated in a narrow band along the shore, the sample from the mid line can not be affected in any degree; and, as regards indicating the pollution from this source, an observation limited to this sample is necessarily in error by 100 per cent. Then, as the pollution is gradually diffused across this line, the density at the line gradually increases; but up to a certain point must still be less than a mean between that half of the area which is proximal and that half which is distal to the shore. The error in this stage must, therefore, always be in one direction, and must vary from 100 per cent to zero.

In the second, or central, area of the cross section the sampling error will likewise be 100 per cent until diffusion has touched the mid line of this area, and will then diminish to zero; and similarly in the distal third of the cross section. Therefore, during this whole period, until diffusion has reached such a stage that the sample from the distal sampling point represents a true mean for that third of the area, the mean density for the entire cross-sectional area will be subject to an error of varying magnitude but always in the same direction, tending to give a result less than the true mean.

At a later stage in the diffusion in each third of the section, after the density at the mid line has reached a true mean, it is perhaps possible that there may be a tendency to a compensating error in the other direction, due to the density at the mid line becoming temporarily greater than the true mean for the corresponding area. Such an error could occur, however, only in special cases, under conditions of mixture which would appear to be most improbable; and at all events it is not a *necessary* occurrence, as are the errors of opposite direction in the earlier stages of mixture. It is only a possibility to be conceived.

From this analysis it may then be concluded:

(1) That sampling errors at cross sections below Cincinnati before the sewage has become thoroughly distributed across the river are likely to be such that the indicated mean for a cross section will be below rather than above the true value.

(2) That such errors will, in general, be more likely to occur and of greater magnitude at the uppermost section (475), where the mixture is least uniform, than at the lower sections, where the mixture is better.

(3) That a higher count observed at a downstream section is consequently a more reliable observation than a lower count at any section above it.

It might also be expected that gross sampling errors at station 475 would be more likely to occur in periods when the mixture there was less uniform than in periods when it was more uniform; and it is of interest to note, in this connection, that during the 13 months included in Table No. 110, in which an increase in bacterial count was observed between stations 475 and 492, the mixture at corresponding sections actually was less uniform than during the 11 months when the maximum count was observed at station 475. This is shown in Table No. 113, following.

TABLE No. 113.—*Relation between location of maximum count and uniformity of mixture at stations below Cincinnati—Percentage which the agar count at each point on each of the four sections, 475, 482, 488, and 492, is of the mean for that section—Means for the period April to November, 1914, 1915, 1916*

Sampling stations	Percentage of section average					
	Mean for 11 months during which maximum count was observed at station 475			Mean for 13 months during which maximum count was observed at station 482, 488, or 492		
	North point	Center point	South point	North point	Center point	South point
Station 475	180	75	45	234	48	18
Station 482	147	96	57	201	69	30
Station 488	117	105	78	156	105	39
Station 492	102	111	87	129	120	51

Significance of increasing counts below Cincinnati.—In summary, two explanations for the frequent increase in bacterial counts observed between stations 475 and 492 have been considered, namely:

(1) That there is a true increase in free cells, due either to actual cell multiplication or to more complete dispersion of cells originally clumped together. The evidence in favor of this is that the maximum count tends to occur within certain fairly definite limits of time below the sewer outlets, suggesting a primary phase of increase, definitely limited in time.

(2) That there is no actual increase in the number of free cells, the apparent increase being attributable to large sampling errors at the upper stations, these errors being more considerable at high than at low river stages. The evidence in favor of this view is that the mixture of sewage with the river, which is by no means uniform at any section in this stretch, is less uniform at the upper than at the lower sections; and that this condition might readily result in systematic sampling errors.

The evidence is not sufficient to establish either explanation as a certain conclusion. Similar analysis of observations grouped primarily by gage heights instead of by months, as in Table No. 114, and of the gelatin counts and *B. coli* determinations in the latter table tends to confirm the facts already presented, but adds nothing to their explanation. The same may also be said of observations at stations 611 and 619, below Louisville, between which there is almost invariably an increase in bacterial counts. A study of results during the winter months, as given in Tables Nos. 110 and 114,

likewise fails to add materially to the evidence, except perhaps to suggest that the phase of increase, if it exists, may extend over a longer period of time in the winter months.

The question whether or not there is a true primary increase in the numbers of free sewage bacteria in the river must, therefore, be left unsettled so far as observations on the Ohio are concerned; and it is not apparent that it would be answered with any certainty even by much more elaborate studies of samples collected at more points on a cross section and from a larger number of sections. However, a study of the Illinois River, made by the Public Health Service in 1920 and 1921, gives some independent evidence of an increase in sewage bacteria in this river below the Chicago Drainage Canal under circumstances where sampling errors similar to those suspected in the Ohio are not competent to explain the phenomenon, and this should perhaps have some weight in the interpretation of the data from the Ohio River. We are, therefore, inclined to believe that the increase so frequently observed in the Ohio River below Cincinnati and Louisville is not wholly due to sampling errors, though recognizing that this is merely an inclination of opinion, influenced by a good many items of indirect evidence and necessarily subject to revision.

Alternative origins from which to reckon time in the study of natural purification.—The uncertainty as to the true significance of the tendency of bacterial counts to increase within the first 10 to 20 miles below Cincinnati results in some uncertainty as to the proper methods to be followed in studying the bacterial death rates in the river.

If it could be accepted as certain that the increased counts below station 475 are due wholly to sampling errors at the stations above, then the proper origin from which to measure the rate and extent of natural purification would be the observed maximum count, whether it occurred at station 475, 482, 488, or 492, since on this hypothesis any lesser bacterial counts upstream from the maximum would be considered as due to errors of observation. On the other hand, if the increased counts below station 475 be considered the result of a real multiplication of cells or disintegration of clumps of sewage bacteria in the river, this primary phase of increase should be taken into account in a study of the changes taking place in the bacterial content of the river. In order to do this it is necessary that time be reckoned not from the observed maximum count, nor from the uppermost sampling station, but from the point where the sewage is discharged into the river, which, in this study, can only be approximated by assuming a certain point on the river as the center of sewer outfalls.

It is believed that the former and simpler method, of disregarding all observations upstream from the highest count, is the more satisfactory, and answers all essential requirements; but before taking it up the data will be presented first from the other viewpoint, relating all the observations to the times elapsing from an origin at the sewer outfalls.

NATURAL PURIFICATION BETWEEN CINCINNATI AND LOUISVILLE IN RELATION TO TIME OF FLOW FROM THE SEWER OUTFALLS OF THE CINCINNATI METROPOLITAN DISTRICT

In order to relate the changes in the bacterial content of the river to the time which has elapsed from the sewer outfalls it is necessary that the observations, which have heretofore been summarized by sampling stations, be regrouped according to time intervals from the sewer outfalls; for, due to changes in the discharge and velocity of the river, the observations made at the upper stations during the periods of low velocity correspond, in point of time elapsed from the sewer outlets, to observations made at lower stations in periods of higher velocity. For example, as shown in Table No. 110, the time of flow from the sewer outfalls to station 492 in November, 1914, was 44.6 hours, while in April, 1916, the time elapsing between this origin and station 598 was approximately the same, 44.8 hours. Similarly, the observations at each station overlap those of one or more lower stations with respect to time; and the aggregate of observations in any except the extreme time intervals may comprise results at two or more stations at different river stages.

Primary grouping of data by river stages.—As the time of flow between successive stations is governed by the river stage, which may vary considerably from day to day within any given month, the monthly mean time of flow—that is, the time corresponding to the mean of daily river stages—may differ widely from the extreme or even from the most frequent times during that month. For example, during the month of October, 1914, with a mean gage height of 3.7 feet, the daily readings varied from 1.3 to 10.1 feet, corresponding to time intervals of about 4.5 and 23 hours, respectively, from sewer outfalls to station 475.

It is preferable, therefore, for a study of purification as related to time, to group the daily bacteriological observations, not according to months or weeks, but according to gage heights on the actual dates of observation; and all counts made during the entire period of three years are shown in Table No. 114, rearranged on this basis. This grouping throws together observations made in different months and years, but under similar conditions of stream flow; and the mean gage height for all the days included in each group varies but little from the extremes. The seasonal grouping is the same as in Table No. 110, the data being grouped separately for a summer period, comprising the months April to November, inclusive, and a winter period, comprising the months December to March.[21]

[21] Observations for the periods December 1 to 13, 1914, and December 1 to 11, 1916, as grouped in these tables, are included in the April–November seasonal period, since the physical and biological conditions during the first part of December in these two years corresponded more closely to those obtained in the autumn than in the winter period. In these two years the seasonal change in the river was quite sudden and definite.

TABLE No. 114.—*Summary of bacteriological observations at all sampling stations between Cincinnati and Louisville, during the years 1914, 1915, and 1916, grouped according to gage heights on dates of sampling, with corresponding mean discharges and mean times of flow from sewer outfalls of Cincinnati to each sampling station*

I. SUMMER, APRIL TO NOVEMBER, 1914, 1915, 1916

Gage height		Discharge (thousand sec.-ft.)	Station 475		Station 482		Station 488		Station 492		Station 543		Station 598	
Range	Mean		Time (hours)	Bacteria per cubic centimeter	Time (hours)	Bacteria per cubic centimeter	Time (hours)	Bacteria per cubic centimeter	Time (hours)	Bacteria per cubic centimeter	Time (hours)	Bacteria per cubic centimeter	Time (hours)	Bacteria per cubic centimeter
Under 2 feet	1.3 feet	8.6	23.1	Agar, *295, 124	51.8	39, 790	62.0	28, 172	66.6	27, 448	195	1, 592	498	173
				Gelatin, *190, 946		39, 614		41, 184		43, 088		1, 835		172
				B. coli, *5, 785		700		496		450		16		3. 1
2–3 feet	2.5 feet	12.0	13.7	Agar, *351, 595	35.9	69, 047	43.5	67, 128	47.6	59, 425	145	1, 258	315	227
				Gelatin, *253, 861		90, 225		87, 596		78, 060		1, 300		239
				B. coli, *4, 006		2, 353		1, 203		712		28		5. 8
3–4 feet	3.4 feet	13.8	11.6	Agar, *262, 046	29.3	47, 539	36.5	39, 875	40.2	41, 290	122	2, 828	258	502
				Gelatin, *195, 082		55, 575		62, 873		68, 805		5, 416		673
				B. coli *8, 237		1, 460		1, 514		1, 359		94		11. 9
4–5 feet	4.4 feet	17.0	10.0	Agar, *115, 711	24.9	104, 167	31.4	75, 310	34.8	72, 994	106	7, 146	219	626
				Gelatin *108, 422		100, 672		90, 219		100, 060		7, 736		928
				B. coli, *4, 078		1, 741		2, 023		1, 482		122		4. 1
5–6 feet	5.3 feet	20.4	8.4	Agar, 97, 122	19.8	*126, 983	25.8	76, 015	29.0	51, 593	91.7	10, 715	192	790
				Gelatin, 77, 595		*124, 796		84, 824		68, 250		21, 051		1, 100
				B. coli, 2, 496		*2, 818		1, 750		1, 762		200		14. 9
6–7 feet	6.5 feet	26.0	6.5	Agar, 88, 168	15.6	*132, 194	21.0	73, 328	23.9	45, 452	77.3	6, 228	162	960
				Gelatin 61, 361		*100, 895		67, 629		39, 655		4, 350		1, 203
				B. coli, 2, 072		*2, 729		2, 018		1, 675		476		3. 4
7–8 feet	7.5 feet	31.6	5.6	Agar, 50, 622	13.6	*73, 649	18.5	72, 529	21.2	57, 182	68.5	13, 684	145	1, 170
				Gelatin, 56, 234		66, 651		*72, 876		58, 757		16, 419		1, 883
				B. coli, 1, 355		*2, 178		1, 538		1, 269		612		33
8–9 feet	8.5 feet	37.6	5.1	Agar, 83, 777	12.1	85, 982	16.6	*104, 981	19.2	75, 703	61.5	16, 670	130	1, 290
				Gelatin, 67, 086		86, 724		*115, 431		81, 307		18, 389		1, 427
				B. col, 1, 536		*2, 502		1, 954		876		325		21. 1
9–10 feet	9.5 feet	43.8	4.7	Agar, 68, 936	10.9	52, 871	15.0	*73, 134	17.4	65, 722	55.6	17, 636	118	2, 378
				Gelatin, 63, 585		49, 948		*74, 163		60, 814		17, 955		2, 417
				B. coli, 1, 214		1, 376		1, 776		*1, 844		178		34. 1

* Indicates maximum count.

Table No. 114.—*Summary of bacteriological observations at all sampling stations between Cincinnati and Louisville, during the years 1914, 1915, and 1916, grouped according to gage heights on dates of sampling, with corresponding mean discharges and mean times of flow from sewer outfalls of Cincinnati to each sampling station*—Continued

I. SUMMER, APRIL TO NOVEMBER, 1914, 1915, 1916—Continued

Gauge height		Discharge (thousand sec.-ft.)	Station 475			Station 482		Station 488		Station 492		Station 543		Station 598	
Rage	Mean		Time (hours)	Bacteria per cubic centimeter		Time (hours)	Bacteria per cubic centimeter	Time (hours)	Bacteria per cubic centimeter	Time (hours)	Bacteria per cubic centimeter	Time (hours)	Bacteria per cubic centimeter	Time (hours)	Bacteria per cubic centimeter
10–12 feet	10.8 feet	51.9	4.2	Agar,	41,000	9.7	34,939	13.4	60,106	15.7	*67,692	49.3	2,370	104	2,205
				Gelatin,	41,840		37,685		59,514		*66,688		30,826		2,829
				B. coli,	*1,629		636		1,287		1,264		402		34.8
12–14 feet	12.8 feet	65.0	3.7	Agar,	42,563	8.3	28,711	11.6	39,597	13.6	*43,381	42.4	28,225	88.2	4,168
				Gelatin,	40,763		33,211		45,023		*48,839		46,545		5,015
				B. coli,	*1,114		1,091		464		992		396		69.5
14–16 feet	14.8 feet	80.4	3.4	Agar,	32,249	7.5	21,160	10.5	27,175	12.3	*34,063	38.2	7,033	76.5	4,204
				Gelatin,	27,176		17,388		24,502		*31,493		17,992		5,643
				B. coli,	1,166		841		801		*1,578		197		88
16–18 feet	17.1 feet	99.7	3.0	Agar,	25,760	6.6	22,108	9.3	37,190	11.0	*42,132	34.5	21,430	66.1	5,287
				Gelatin,	25,590		23,967		35,693		*48,998		35,750		7,307
				B. coli,	771		615		776		*1,308		336		75
18–20 feet	18.9 feet	115.2	2.8	Agar,	*25,962	6.1	17,918	8.6	16,969	10.2	15,272	32.2	18,441	59.9	4,141
				Gelatin,	19,414		17,178		16,200		17,215		*21,700		7,177
				B. coli,	659		516		*780		313		417		80
20–25 feet	22.1 feet	145.0	2.6	Agar,	11,838	5.6	11,693	7.9	10,766	9.4	*12,868	29.9	8,233	52.8	4,909
				Gelatin,	16,089		13,963		14,150		*16,614		13,072		11,287
				B. coli,	*434		336		267		306		174		117
25–30 feet	26.9 feet	191.4	2.3	Agar,	6,759	5.1	4,910	7.2	5,454	8.6	7,889	26.6	*8,291	46.2	3,896
				Gelatin,	12,588		9,195		8,675		11,490		*14,842		7,783
				B. coli,	*208		118		158		100		--------		70
30–40 feet	36.3 feet	288.3	2.0	Agar,	3,972	4.4	*5,312	6.2	2,754	7.5	3,661	22.6	2,767	39.8	2,232
				Gelatin,	10,362		10,965		9,537		*11,637		11,142		6,500
				B. coli,	110		*165		64		90		70		51
40 feet and over	43.5 feet	399.2	1.9	Agar,	3,204	3.6	3,236	5.2	2,839	6.4	*3,459	18.9	2,667	34.7	2,186
				Gelatin,	13,303		12,500		11,689		13,011		9,167		*15,179
				B. coli,	125		155		150		*270		70		25

II. WINTER, DECEMBER, JANUARY, FEBRUARY, AND MARCH, 1914, 1915, 1916

Under 10 feet	8.1 feet	35.0	4.6	Agar, Gelatin, B. coli,	*3,881 *10,902 *306	11.6	1,702 7,660 178	16.8	2,291 9,496 160	19.4	3,462 17,912 223	63.9	1,165 7,771 25	135.9	715 5,367 11
10–12 feet	11.0 feet	53.1	3.7	Agar, Gelatin, B. coli,	*3,750 *11,957 *465	9.1	1,633 7,243 125	12.8	1,774 8,457 120	15.0	2,447 9,721 143	48.0	1,190 6,189 54	107.5	725 3,591 8.5
12–14 feet	13.1 feet	67.4	3.4	Agar, Gelatin, B. coli,	*2,780 *13,095 *332	8.0	1,178 8,536 62	11.2	1,483 7,421 75	13.2	1,716 7,861 166	41.7	1,229 4,883 46	86.7	783 3,953 18
14–16 feet	14.7 feet	78.1	3.3	Agar Gelatin, B. coli,	*3,147 *32,588 219	7.4	1,256 24,609 103	10.4	487 24,639 150	12.3	756 27,669 *260	38.4	418 23,462 40	77.2	1,376 11,680 39
16–18 feet	17.0 feet	98.7	3.0	Agar, Gelatin, B. coli,	*2,781 *12,501 *206	6.6	1,351 9,244 69	9.4	1,184 6,002 59	11.0	1,570 6,521 96	34.6	1,646 7,550 32	66.6	1,305 8,119 28
18–20 feet	18.9 feet	115.2	2.8	Agar, Gelatin, B. coli,	3,146 *22,560 134	6.2	2,283 13,278 93	8.7	2,891 17,402 *146	10.3	*5,325 19,926 88	32.3	2,256 12,199 70	60.3	1,784 10,863 35
20–25 feet	22.6 feet	149.5	2.5	Agar, Gelatin B. coli,	*2,917 *22,829 *160	5.5	2,337 20,173 96	7.8	1,815 14,008 70	9.2	2,689 17,674 103	29.2	2,237 16,763 59	52.2	2,453 20,511 41
25–30 feet	27.1 feet	193.4	2.3	Agar, Gelatin, B. coli,	2,855 22,003 134	5.1	2,575 19,112 94	7.2	3,427 22,696 106	8.5	*4,233 21,286 156	26.5	3,277 20,063 *174	46.0	4,033 *26,129 84
30–35 feet	31.8 feet	232.5	2.2	Agar, Gelatin, B. coli,	2,693 20,014 97	4.7	2,567 19,862 131	6.6	2,673 16,279 82	7.9	2,898 18,011 118	24.4	*3,453 *23,752 *189	42.4	3,173 22,479 48
35–40 feet	37.5 feet	301.0	1.8	Agar, Gelatin, B. coli,	4,602 28,556 *228	4.2	4,762 31,531 138	6.0	4,459 30,728 137	7.3	5,903 37,014 139	22.3	*7,431 39,411 117	39.4	6,653 *47,165 140
40 feet and over	44.8 feet	377.8	1.7	Agar, Gelatin, B. coli,	4,481 28,657 157	3.9	4,594 28,550 152	5.6	4,109 27,470 145	6.8	4,638 33,084 *197	19.3	5,187 35,463 130	34.7	*5,996 *38,742 81

* Indicates maximum count.

Methods of averaging observations in similar time intervals.—When the counts in this table are arrayed according to time intervals from the origin, observations at the upper stations at low river stages, with small dilution of the sewage and correspondingly high bacterial counts, are brought together with observations at the lower stations at high river stages, with greater dilution and correspondingly low counts. For instance, within the time range from 20 to 25 hours are included observations as follows:

(1) Station	(2) Gage height	(3) Discharge	(4) Bacteria per cubic centimeter	(5) Quantity units
475	1. 3	8,600 second-feet	295, 000	2, 538, 000
482	4. 4	17,000 second-feet	104, 000	2, 590, 000
488	6. 5	26,000 second feet	73, 300	1, 907, 000
492	6. 5	26,000 second-feet	45, 500	1, 182, 000
492	7. 5	31,600 second-feet	57, 200	1, 807, 000
543	36. 3	288,300 second-feet	2, 770	798, 000
		Mean	96, 300	1, 637, 000

The mean of the numbers of bacteria per cubic centimeter as calculated from the figures given in column (4) has no clear significance, because the counts are determined in part by the time which has elapsed, in part by the dilution, which in this instance varies from 8,600 to 288,000 second-feet.

The observations may, however, be reduced to a comparable basis by converting the data into terms of "quantity units," multiplying each count by the corresponding discharge. This eliminates differences due to varying dilution; and, as counts under otherwise comparable conditions are in a general way inversely proportional to discharge, the values to be averaged fall within a much narrower range of dispersion, as illustrated by the figures in column (5) of the above example.

This would be a satisfactory method for treating the data for the seasonal period from April to November, for it brings corresponding values to comparable magnitudes; but as applied to the winter observations it has the opposite effect. Thus, referring to Table No. 114, it will be noted that the counts immediately below Cincinnati do not tend, in the winter months, to be inversely proportional to the discharge, but rather to be of the same order or even to increase with increasing discharge.

An alternative treatment, which is equally applicable to the summer and the winter data, is to take the maximum count observed in each series of observations at each river stage as a base (=100) and to reduce the other observations in that series to percentages of that base, as in Table No. 115. Then, in regrouping according to time intervals, these percentages or index numbers are averaged. This gives equal weight to all observations and takes account only of variations with respect to the maximum which is the variation that it is desired to measure. All things considered, this seems to be the method best adapted for this analysis.

Table No. 115.—*Summary of bacteriological observations at all sampling stations between Cincinnati and Louisville, during the years 1914, 1915, and 1916, grouped according to gage heights on dates of sampling, showing percentage which the count at each sampling station is of the count at station showing highest count in corresponding gage-height series; also times of flow from sewer outfalls of Cincinnati to each station*

I. SUMMER, APRIL TO NOVEMBER, 1914, 1915, AND 1916

Gage height, feet		Discharge (thousand sec.-ft.)	Station 475			Station 482		Station 488		Station 492		Station 543		Station 598	
Range	Mean		Time (hours)	Percentage of maximum count		Time (hours)	Percentage of maximum count	Time (hours)	Percentage of maximum count	Time (hours)	Percentage of maximum count	Time (hours)	Percentage of maximum count	Time (hours)	Percentage of maximum count
Under 2 feet	1.3	8.6	23.1	Agar,	100.00	51.8	13.48	62.0	9.55	66.6	9.30	194.7	0.54	497.7	0.059
				Gelatin,	100.00		20.75		21.57		22.57		.96		.090
				B. coli,	100.00		12.10		8.57		7.78		.29		.054
2–3 feet	2.5	12.0	13.7	Agar,	100.00	35.4	19.64	43.5	19.09	47.6	16.90	144.8	.36	314.8	.065
				Gelatin,	100.00		35.54		34.51		30.75		.51		.094
				B. coli,	100.00		58.74		30.03		17.77		.70		.145
3–4 feet	3.4	13.8	11.6	Agar,	100.00	29.3	18.14	36.5	15.22	40.2	15.76	122.2	1.08	258.2	.192
				Gelatin,	100.00		28.49		32.23		35.27		2.78		.34
				B. coli,	100.00		17.72		18.38		16.50		1.14		.144
4–5 feet	4.4	17.0	10.0	Agar,	100.00	24.9	80.02	31.4	65.08	34.8	63.08	105.7	6.18	219.2	.541
				Gelatin,	100.00		92.85		83.21		92.29		7.14		.86
				B. coli,	100.00		42.69		49.61		36.34		12.80		.101
5–6 feet	5.3	20.4	8.4	Agar,	76.48	19.8	100.00	25.8	59.86	29.0	40.63	91.7	8.44	191.6	.622
				Gelatin,	62.18		100.00		67.97		54.69		16.87		.88
				B. coli,	88.57		100.00		62.10		62.53		7.10		.529
6–7 feet	6.5	26.0	6.5	Agar,	66.70	15.6	100.00	21.0	55.47	23.9	34.38	77.3	4.71	162.4	.726
				Gelatin,	60.82		100.00		67.03		39.30		4.31		1.19
				B. coli,	75.93		100.00		73.95		61.38		17.44		.124
7–8 feet	7.5	31.6	5.6	Agar,	68.73	13.6	100.00	18.5	98.48	21.2	77.64	68.5	18.58	144.7	1.59
				Gelatin,	77.16		91.46		100.00		80.63		22.53		2.58
				B. coli,	62.21		100.00		70.62		58.26		28.10		1.52
8–9 feet	8.5	37.6	5.1	Agar,	79.80	12.1	81.90	16.6	100.00	19.2	72.11	61.5	15.88	130.2	1.23
				Gelatin,	58.12		75.13		100.00		70.44		15.93		1.24
				B. coli,	61.39		100.00		78.10		35.01		12.99		.843
9–10 feet	9.5	43.8	4.7	Agar,	94.26	10.9	72.29	15.0	100.00	17.4	89.87	55.6	24.11	118.1	3.25
				Gelatin,	85.74		67.35		100.00		82.00		24.21		3.26
				B. coli,	65.84		74.62		96.31		100.00		9.65		1.85

Table No. 115.—*Summary of bacteriological observations at all sampling stations between Cincinnati and Louisville, during the years 1914, 1915, and 1916, grouped according to gage heights on dates of sampling, showing percentage which the count at each sampling station is of the count at station showing highest count in corresponding gage-height series; also times of flow from sewer outfalls of Cincinnati to each station*—Continued

I. SUMMER, APRIL TO NOVEMBER, 1914, 1915, AND 1916—Continued

Gage height, feet		Discharge (thousand sec.-ft.)	Station 475		Station 482		Station 488		Station 492		Station 543		Station 598	
Range	Mean		Time (hours)	Percentage of maximum count	Time (hours)	Percentage of maximum count	Time (hours)	Percentage of maximum count	Time (hours)	Percentage of maximum count	Time (hours)	Percentage of maximum count	Time (hours)	Percentage of maximum count
10–12 feet	10.8	51.9	4.2	Agar, 60.57	9.7	51.61	13.4	88.79	15.7	100.00	49.3	3.50	104.4	3.30
				Gelatin, 62.74		56.51		89.24		100.00		46.22		4.24
				B. coli, 100.00		39.04		79.01		77.59		24.68		2.14
12–14 feet	12.8	65.0	3.7	Agar, 98.11	8.3	66.18	11.6	91.28	13.6	100.00	42.4	65.06	88.2	9.61
				Gelatin, 83.46		68.00		92.19		100.00		95.30		10.27
				B. coli, 100.00		97.94		41.65		89.05		35.55		6.24
14–16 feet	14.8	80.4	3.4	Agar, 94.67	7.5	62.12	10.5	79.78	12.3	100.00	38.2	20.65	76.5	12.34
				Gelatin, 86.30		55.22		77.80		100.00		57.13		17.92
				B. coli, 73.89		53.30		50.76		100.00		12.48		5.58
16–18 feet	17.1	99.7	3.0	Agar, 61.14	6.6	52.48	9.3	88.27	11.0	100.00	34.5	50.87	66.1	12.55
				Gelatin, 52.23		48.91		72.85		100.00		72.96		14.91
				B. coli, 58.94		47.02		59.33		100.00		25.69		5.74
18–20 feet	18.9	115.2	2.8	Agar, 100.00	6.1	69.02	8.6	65.36	10.2	58.83	32.2	71.03	59.9	15.95
				Gelatin, 89.47		79.16		74.65		79.33		100.00		33.07
				B. coli, 84.49		66.15		100.00		40.13		53.46		10.29
20–25 feet	22.1	145.0	2.6	Agar, 92.00	5.6	90.88	7.9	83.67	9.4	100.00	29.4	63.99	52.8	38.16
				Gelatin, 96.84		84.04		85.17		100.00		78.68		67.94
				B. coli, 100.00		77.42		61.52		70.51		40.09		26.96
25–30 feet	26.9	191.4	2.3	Agar, 81.52	5.1	59.22	7.2	65.78	8.6	95.15	26.6	100.00	46.2	46.99
				Gelatin, 84.81		61.95		58.45		77.42		100.00		52.44
				B. coli, 100.00		56.73		75.96		47.93		17.16		62.50
30–40 feet	36.3	288.3	2.0	Agar, 74.79	4.4	100.00	6.2	51.96	7.5	68.94	22.6	52.11	39.8	42.04
				Gelatin, 89.04		94.23		81.95		100.00		95.75		55.86
				B. coli, 12.22		18.33		71.11		100.00		77.78		5.71
40 feet and over	43.5	399.2	1.9	Agar, 92.66	3.6	93.58	5.2	82.10	6.4	100.00	18.9	77.13	34.7	63.23
				Gelatin, 87.64		82.35		77.01		85.72		60.39		100.00
				B. coli, 46.30		57.41		55.56		100.00		25.93		9.26

II. WINTER, DECEMBER, JANUARY, FEBRUARY, AND MARCH, 1914, 1915, AND 1916

Under 10 feet	8.1	35.0	4.6	Agar,	100.00	11.6	43.8	16.8	59.0	19.4	89.1	63.9	30.0	135.9	18.4
				Gelatin,	60.86		42.76		53.01		100.00		43.38		29.96
				B. coli,	100.00		58.17		52.29		72.88		8.17		3.59
10–12 feet	11.0	53.1	3.7	Agar,	100.00	9.1	43.6	12.8	47.3	15.0	62.6	48.0	31.7	107.5	19.4
				Gelatin,	100.00		60.58		70.73		81.30		51.76		30.03
				B. coli,	100.00		26.88		25.81		30.75		11.51		1.83
12–14 feet	13.1	67.4	3.4	Agar,	100.00	8.0	42.4	11.2	53.7	13.2	61.6	41.7	44.2	86.7	28.2
				Gelatin,	100.00		65.19		56.67		60.03		37.29		30.19
				B. coli,	100.00		18.80		22.71		50.00		13.86		5.42
14–16 feet	14.7	78.1	3.3	Agar,	100.00	7.4	39.9	10.4	15.5	12.3	24.0	38.4	13.3	77.2	43.7
				Gelatin,	100.00		75.52		75.61		84.91		72.00		35.84
				B. coli,	84.23		39.62		57.69		100.00		15.38		15.00
16–18 feet	17.0	98.7	3.0	Agar,	100.00	6.6	48.6	9.4	42.6	11.0	56.5	34.6	59.2	66.6	46.9
				Gelatin,	100.00		73.95		48.01		52.16		60.40		64.95
				B. coli,	100.00		33.45		28.54		46.75		15.78		13.83
18–20 feet	18.9	115.2	2.8	Agar,	59.10	6.2	42.9	8.7	54.7	10.3	100.0	32.3	42.4	60.3	33.5
				Gelatin,	100.00		58.86		77.14		88.32		54.07		48.15
				B. coli,	91.78		63.42		100.00		59.93		47.95		24.25
20–25 feet	22.6	149.5	2.5	Agar,	100.00	5.5	80.1	7.8	62.2	9.2	92.0	29.2	76.7	52.2	84.0
				Gelatin,	100.00		88.37		61.36		77.42		73.43		89.85
				B. coli,	100.00		60.06		43.56		64.38		37.06		25.56
25–30 feet	27.1	193.4	2.3	Agar,	67.50	5.1	60.9	7.2	81.0	8.5	100.0	26.5	77.4	46.0	95.2
				Gelatin,	84.21		73.14		86.86		81.47		76.78		100.00
				B. coli,	77.01		54.25		60.92		89.66		100.00		48.51
30–35 feet	31.8	232.5	2.2	Agar,	78.20	4.7	74.5	6.6	77.5	7.9	84.0	24.4	100.00	42.4	92.0
				Gelatin,	84.26		83.62		68.54		75.83		100.00		94.64
				B. coli,	51.16		69.31		43.49		62.43		100.00		25.34
35–40 feet	37.5	301.0	1.8	Agar,	60.60	4.2	64.0	6.0	60.0	7.3	79.5	22.3	100.0	39.4	89.5
				Gelatin,	60.54		66.85		65.15		78.48		83.56		100.00
				B. coli,	100.00		60.53		60.09		60.96		51.32		61.40
40 feet and over	44.8	377.8	1.7	Agar,	74.60	3.9	76.6	5.6	68.4	6.8	77.3	19.3	86.5	34.7	100.0
				Gelatin,	73.97		73.69		70.90		85.40		91.54		100.00
				B. coli,	79.70		77.16		73.60		100.00		65.99		41.07

Extent and rates of decrease in summer months.—Table No. 116, showing the data pertaining to agar counts from Table No. 115 regrouped according to time intervals from sewer outfalls, will serve to illustrate the method of assembling the data and to give an idea of their consistency. It will be noted that the percentages of the maximum which fall into any one time interval, especially in the shorter times in the first portion of the table, vary quite widely, but that, when averaged, they show a quite definite trend, first increasing somewhat irregularly to a maximum in the time interval 15–20 hours, then decreasing quite regularly in each successive time interval thereafter. Since the maxima (100 per cent) of the several series, corresponding to different gage heights, fall into different time intervals, along with other observations ranging as low as 50 per cent or less, the highest mean for any time interval is 93.06 per cent in the time interval 15–20 hours.

TABLE No. 116.—*Data from Table No. 115 regrouped according to times of flow from sewer outfalls, agar counts, summer months*

Sampling station	Gage height	Time of flow	Bacteria, per cent of maximum
TIME UNDER 5 HOURS			
475	9.5	4.7	94.26
475	10.8	4.2	60.57
475	12.8	3.7	98.11
475	14.8	3.4	94.67
475	17.1	3.0	61.14
475	18.9	2.8	100.00
475	22.1	2.6	92.00
475	26.9	2.3	81.52
475	36.3	2.0	74.79
475	43.5	1.9	92.66
482	36.3	4.4	100.00
482	43.5	3.6	93.58
Means	24.9	3.2	86.94
TIME 5–10 HOURS			
475	5.3	8.4	76.48
475	6.5	6.5	66.70
475	7.5	5.6	68.73
475	8.5	5.1	79.80
482	10.8	9.7	51.61
482	12.8	8.3	66.18
482	14.8	7.5	62.12
482	17.1	6.6	52.48
482	18.9	6.1	69.02
482	22.1	5.6	90.88
482	26.9	5.1	59.22
488	17.1	9.3	88.27
488	18.9	8.6	65.36
488	22.1	7.9	83.67
488	26.9	7.2	65.78
488	36.3	6.2	51.96
488	43.5	5.2	82.10
492	22.1	9.4	100.00
492	26.9	8.6	95.15
492	36.3	7.5	68.94
492	43.5	6.4	100.00
Means	21.2	7.2	73.55
TIME 10–15 HOURS			
475	2.5	13.7	100.00
475	3.4	11.6	100.00
475	4.4	10.0	100.00
482	7.5	13.6	100.00
482	8.5	12.1	81.90
482	9.5	10.9	72.29
488	10.8	13.4	88.79
488	12.8	11.6	91.28
488	14.8	10.5	79.78
492	12.8	13.6	100.00
492	14.8	12.3	100.00
492	17.1	11.0	100.00
492	18.9	10.2	58.83
Means	10.6	11.9	90.22
TIME 15–20 HOURS			
482	5.3	19.8	100.00
482	6.5	15.6	100.00
488	7.5	18.5	98.48
488	8.5	16.6	100.00
488	9.5	15.0	100.00
492	8.5	19.2	72.11
492	9.5	17.4	89.87
492	10.8	15.7	100.00
543	43.5	18.9	77.13
Means	12.1	17.4	93.06
TIME 20–30 HOURS			
475	1.3	23.1	100.00
482	3.4	29.3	18.14
482	4.4	24.9	80.02
488	5.3	25.8	59.86
488	6.5	21.0	55.47
492	5.3	29.0	40.63
492	6.5	23.9	34.38
492	7.5	21.2	77.64
543	22.1	29.4	63.99
543	26.9	26.6	100.00
543	36.3	22.6	52.11
Means	11.4	25.2	62.02

TABLE No. 116.—*Data from Table No. 115 regrouped according to times of flow from sewer outfalls, agar counts, summer months*—Continued

Sampling station	Gage height	Time of flow	Bacteria, per cent of maximum
TIME 30–40 HOURS			
482	2.5	35.4	19.64
488	3.4	36.5	15.22
488	4.4	31.4	65.08
492	4.4	34.8	63.08
543	14.8	38.2	20.65
543	17.1	34.5	50.87
543	18.9	32.2	71.03
598	36.3	39.8	42.037
598	43.5	34.7	63.226
Means	16.1	35.3	45.648
TIME 40–50 HOURS			
488	2.5	43.5	19.09
492	2.5	47.6	16.90
492	3.4	40.2	15.76
543	10.8	49.3	3.50
543	12.8	42.4	65.06
598	26.9	46.2	46.991
Means	9.8	44.8	27.884
TIME 50–75 HOURS			
482	1.3	51.8	13.48
488	1.3	62.0	9.55
492	1.3	66.6	9.30
543	7.5	68.5	18.58
543	8.5	61.5	15.88
543	9.5	55.6	24.11
598	17.1	66.1	12.551
598	18.9	59.9	15.954
598	22.1	52.8	38.157
Means	9.7	60.5	17.507

Sampling station	Gage height	Time of flow	Bacteria per cent of maximum
TIME 75–100 HOURS			
543	5.3	91.7	8.44
543	6.5	77.3	4.71
598	12.8	88.2	9.608
598	14.8	76.5	12.342
Means	9.8	83.4	8.775
TIME 100–125 HOURS			
543	3.4	122.2	1.08
543	4.4	105.7	6.18
543	9.5	118.1	3.251
543	10.8	104.4	3.302
Means	7.0	112.6	3.453
TIME 125–150 HOURS			
543	2.5	144.8	0.36
598	7.5	144.7	1.589
598	8.5	130.2	1.229
Means	6.1	139.9	1.059
TIME 150–200 HOURS			
543	1.3	194.7	0.54
598	5.3	191.6	.622
598	6.5	162.4	.726
Means	4.3	182.9	.629
TIMES OVER 200 HOURS			
598	4.4	219.2	0.541
598	3.4	258.2	.192
598	2.5	314.8	.065
598	1.3	497.7	.059
Means	2.9	322.5	.214

The means corresponding to each time interval as shown in this table are summarized in Table No. 117, together with mean values for the gelatin counts and *B. coli* determinations similarly derived from Table No. 115. In column (7) of this table the highest value shown in column (4) (93.06 per cent) is taken as a base = 100 per cent, and the remaining values expressed as percentages of this maximum. The data for gelatin counts and *B. coli* are given in columns (8) and (9), transferred to a similar basis.

TABLE No. 117.—*Percentages which the bacteria remaining at stated times below the sewer outfalls of the Cincinnati metropolitan district are of the numbers observed in the zone of maximum pollution below that district, April to November, inclusive, 1914, 1915, 1916*

Time range	Mean gage height	Mean time from sewer outlets	Means of percentages of maxima			Reduced to basis of 100 per cent at maximum		
			Agar	Gelatin	B. coli	Agar	Gelatin	B. coli
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Feet	*Hours*						
Under 5.0 hours	24. 9	3. 2	86. 94	82. 90	68. 12	93. 52	91. 79	82. 36
5–10 hours	21. 2	7. 2	73. 55	72. 54	69. 89	79. 04	80. 32	84. 50
10–15 hours	10. 6	11. 9	90. 22	90. 19	82. 71	96. 95	99. 87	100. 00
15–20 hours	12. 1	17. 4	93. 06	90. 31	75. 95	100. 00	100. 00	91. 83
20–30 hours	11. 4	25. 2	62. 02	73. 22	55. 79	66. 65	81. 08	67. 45
30–40 hours	16. 1	35. 3	45. 65	69. 91	30. 46	49. 05	77. 41	36. 83
40–50 hours	9. 8	44. 8	27. 88	49. 08	31. 16	29. 96	54. 35	37. 67
50–75 hours	9. 7	60. 5	17. 51	27. 05	13. 57	18. 82	29. 95	16. 41
75–100 hours	9. 8	83. 4	8. 78	12. 34	9. 09	9. 43	13. 66	10. 99
100–125 hours	7. 0	112. 6	3. 45	4. 35	4. 48	3. 71	4. 82	5. 42
125–150 hours	6. 1	139. 9	1. 06	1. 44	1. 021	1. 14	1. 59	1. 23
150–200 hours	4. 3	182. 9	. 63	1. 01	. 314	. 68	1. 12	. 380
200 hours and over	4. 4	219. 2	. 54	. 86	. 101	. 58	. 95	. 122
	3. 4	258. 2	. 192	. 34	. 144	. 21	. 38	. 174
	2. 5	314. 8	. 065	. 094	. 145	. 070	. 104	. 175
	1. 3	497. 7	. 059	. 090	. 054	. 063	. 100	. 065

The trend and consistency of the observations when thus grouped are better shown in Figure No. 32, representing the agar counts, in which the percentages of the maximum count are plotted as ordinates against corresponding times of flow from the sewer outlets as abscissae.[22] As described by these curves,[23] the bacterial count increases from the sewer outlets to a maximum which is not at all definitely located by the observations, but falls apparently at an interval of about 12.5 hours from the sewer outlets. From this point the count decreases rapidly and quite regularly throughout the remainder of the range of observations, so that, as shown in the table, the bacteria remaining after 183 hours are less than 1 per cent of the maximum; and after 315 hours are less than one-tenth of 1 per cent.

It will be seen from the figure that the two curves, which have been drawn through the points indicated by the data of Table No. 117, are more clearly defined in some portions than in others. Thus, from the origin to the crest of the curves, the observations are quite scattered and irregular, so that as to this portion of the curves there is no certainty, except that the general tendency is upwards,

[22] Graphic representations of the data relating to gelatin counts and *B. coli* are not reproduced here, as it is obvious from the data given in Table No. 117 that the curves would be similar to those showing the agar counts. Curves fitted to the data by simple inspection compare with those shown for the agar counts as follows: The maximum is reached in about 15 hours in the gelatin count, in 10 hours in the *B. coli*. In the gelatin count the rate of decrease from the maximum appears somewhat less rapid than in the agar count, while the rate of decrease in *B. coli* appears more rapid.

[23] The two curves shown correspond to two separate fittings of the data. (See Tables Nos. 118 and 119 and explanatory text.)

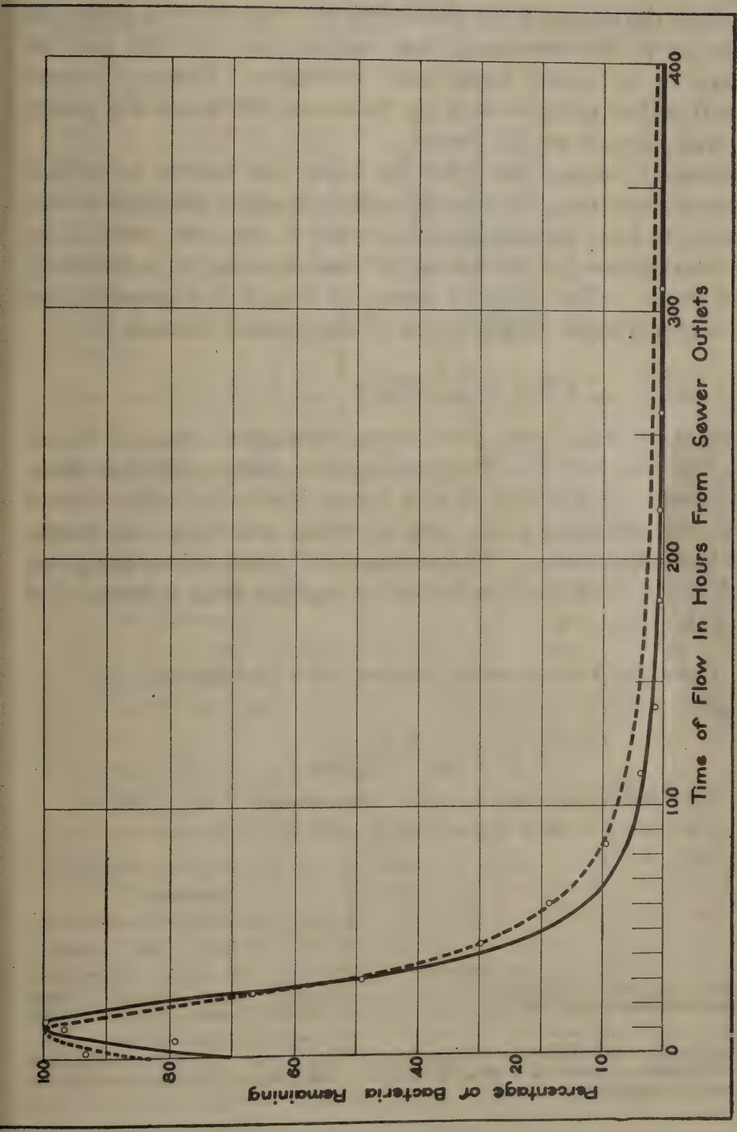

FIG. 32.—Bacterial purification in Ohio River between Cincinnati and Louisville in relation to time of flow from sewer outfalls of Cincinnati metropolitan district. Agar counts: Summer months, April–November, 1914, 1915, and 1916. Percentages which the bacteria remaining at any time are of the numbers observed in the zone of maximum pollution

Points (o) indicate actual observations (Table No. 117).
———=Curve A, Tables Nos. 118 and 119.
- - - - - -=Curve B, Tables Nos. 118 and 119

toward a maximum, the position of which can only be approximated. The descending limb of the curves, from the crest, or still better from about 25 hours to about 140 hours, is quite well defined. At times beyond about 140 hours the points lie so close to the base line that their deviations from the curve can not be well indicated graphically except by increasing the vertical scale in this portion of the curve or by using logarithmic ordinates. Either of these methods will suffice to show that up to about 300 hours the points are fairly well aligned on the curves.

Formulation of curves.—In order to define the curves somewhat more precisely than may be done by simple graphic methods alone, several attempts have been made, in the case of the agar count data, to fit the observations, by the method of least squares, to a definitely formulated curve. The type of curve to which the observations appear to conform most closely is one of the general formula:

$$y = \frac{b}{1 + (cx + d)e^{ax}} \; *$$

Two curves of this type have been developed, one of which (curve A, fig. No. 32) fits the data quite satisfactorily at times beyond 100 hours, but not at shorter times; while the other (curve B, fig. No. 32) fits them fairly well at times less than 100 hours, but not at the longer times. The constants of these curves are given in Table No. 118, and their ordinates at regular time intervals are shown in Table No. 119.

TABLE NO. 118.—*Constants of curves shown in Figure 32*

Formula:

$$y = \frac{b}{1 + (cx + d)10^{ax}}$$

y = bacteria (percentage of maximum).
x = time of flow from sewer outfalls, hours.

	Constants			
	(a)	(b)	(c)	(d)
A. Curve of better fit for times over 100 hours	0.003435	0.2094	0.003284	−0.9970
B. Curve of better fit for times under 100 hours	−.007116	1.0849	−.007558	−.9865

* We are indebted to Dr. Lowell J. Reed, of the department of biometry and vital statistics of the Johns Hopkins University School of Hygiene and Public Health, for the suggestion of this type of curve and for assistance in fitting the data to it.

TABLE No. 119.—*Ordinates of curves A and B, Figure No. 32, computed from formulæ of Table No. 118, agar counts, April to November*

[Curve A = curve of better fit for times greater than 100 hours. Curve B = curve of better fit for times less than 100 hours]

Time of flow from sewer outfalls (x)	Per cent of maximum numbers of bacteria (y)		Time of flow from sewer outfalls (x)	Per cent of maximum numbers of bacteria (y)	
	Curve A	Curve B		Curve A	Curve B
0 hour	70.36	80.36	175 hours	0.912	3.23
5 hours	86.14	94.47	200 hours	.647	2.73
10 hours	96.77	99.57	225 hours	.475	2.37
15 hours	99.90	95.04	250 hours	.358	2.11
20 hours	86.07	81.76	275 hours	.276	1.91
30 hours	52.34	53.95	300 hours	.217	1.76
40 hours	30.74	35.61	325 hours	.172	1.64
50 hours	18.88	24.62	350 hours	.139	1.55
60 hours	12.40	17.96	375 hours	.113	1.48
70 hours	8.61	13.73	400 hours	.093	1.41
80 hours	6.27	10.90	425 hours	.077	----------
90 hours	4.72	8.93	450 hours	.064	----------
100 hours	3.66	7.49	475 hours	.054	----------
125 hours	2.12	5.25	500 hours	.045	----------
150 hours	1.35	4.00			

NOTE.—Maximum point for both curves located at 12.5 hours below sewer outlets.

As is shown later, curves of much simpler type may be fitted more satisfactorily to the descending limb of the curve, and as it is this portion of the curve which is of most definite significance and importance, it has not seemed worth while to continue the attempt to fit the data to these much more complex "crested" curves, nor to extend the trials to the gelatin count and *B. coli* data for the summer period, April to November.

Extent and rates of decrease in winter months.—So far the discussion has referred solely to the observations made during the months from April to November, inclusive. The observations during the winter months, December to March, inclusive, are much less regular and of somewhat different trend.

Referring to Table 114, it will be noted first, that, whereas during the summer months the bacterial counts at the upper stations decrease very regularly as the discharge increases, there is no such tendency during the winter months, the bacterial counts remaining nearly constant or actually increasing while the discharge increases more than tenfold. This reversal during the winter months of the relation between discharge and concentration of bacteria below Cincinnati may be accounted for by two facts which have already been pointed out, namely:

(1) The total number of bacteria added in the sewage of the metropolitan district is much less (about one-tenth) in winter than in summer (see Table No. 103, page 246).

(2) The bacterial count in the river as it reaches Cincinnati (station 461) is much higher in winter and during periods of high discharge than in summer and in periods of low discharge. Consequently, the bacteria added in the sewage of the Cincinnati district constitute only a small proportion of those found below the city

during the winter months, a proportion which decreases rapidly as discharge increases.

There is, then, this important difference between summer and winter conditions: In summer, even at relatively high river stages, the bacteria found in the river immediately below Cincinnati are chiefly those recently added in the sewage from that district, and their concentration is inversely proportional to the discharge of the river. In winter these freshly added sewage bacteria constitute only a small proportion of the total, the greater portion being made up of bacteria brought down the river from above. It need not be surprising, then, that the winter flora reacts quite differently from the summer flora, since it is of different origin and history.

It may be seen, further, from Table No. 114, that at gage heights less than 25 feet there is always a net *decrease* in the bacterial count between stations 475 and 598, but that at gage heights over 25 feet the tendency, with some exceptions in the case of *B. coli*, is in the opposite direction, the counts being *higher* at station 598 than at station 475. That is to say, when the river is at high stages, such that the time interval from sewer outlets to station 598 is less than 50 hours, there is no net "purification" within the entire stretch in winter.[24]

Even at gage heights under 25 feet, the sequence of observations at sucessive stations is very irregular. The highest count is usually at station 475. This is followed by considerably reduced counts at station 482 and usually also at station 488, with higher counts again at station 492,[25] after which there is a fairly consistent decline at stations 543 and 598. No adequate explanation can be offered for this "dipping" of the counts between stations 475 and 492. It is difficult to believe that the bacteria present at station 475 have already decreased by 50 per cent or more in the short interval between that section and the next station, No. 482, and then have materially increased again before reaching station 492. The fluctuations are, however, too great and too regular to be accounted for by ordinary random errors of sampling; and a study of results at individual sampling points on these sections gives no clue to irregularities of mixture which would account for the observations.

All that may be said, then, of the observations between stations 475 and 492 is that they are so erratic as to be quite unintelligible and subject to the suspicion of some gross error. If these stations (482 and 488) are disregarded, then, at river stages less than 25 feet, there is, at the other four sampling stations, a consistent decrease between stations 475 and 598, which is in general progressive, each sampling station showing usually a lower count than the station next above. Even this general tendency does not hold, however, as regards the ob-

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[24] At corresponding gage heights n the summer months there is always some, usually a considerable decrease in counts between stations 475 and 598.

[25] The increase in counts at station 492 is more than can be accounted for by the inflow of the Miami.

servations at high river stages, when the time from Cincinnati to station 598 is less than 50 hours.

If all the observations during the winter months are grouped and treated in the same manner as the observations during the summer months, the results are as shown in Table No. 120 and Figures 33, 34 and 35.

TABLE No. 120.—*Percentages which the bacteria remaining at stated times below sewer outfalls of the Cincinnati metropolitan district are of the numbers observed in the zone of maximum pollution below that district—Winter months, December to March, inclusive, 1914, 1915, 1916*

Time range	Number of items	Mean gage height	Mean time from sewer outlets	Per cent of maximum count					
				As found			Reduced to basis of 100 per cent at maximum		
				Agar	Gelatin	B. coli	Agar	Gelatin	B. coli
		Feet	*Hours*						
Under 5.0 hours	14	25. 8	3. 1	82. 51	84. 86	85. 06	95. 92	100. 00	100. 00
5–10 hours	19	25. 7	7. 3	65. 14	72. 22	57. 06	75. 73	85. 10	67. 09
10–15 hours	8	13. 8	11. 6	50. 30	66. 40	52. 63	58. 47	78. 25	61. 87
15–20 hours	4	18. 0	17. 6	74. 30	81. 46	55. 48	86. 38	95. 99	65. 22
20–30 hours	4	29. 8	25. 6	86. 02	83. 44	72. 10	100. 00	98. 33	84. 76
30–40 hours	5	26. 6	35. 9	60. 88	77. 29	36. 32	70. 77	91. 08	42. 70
40–50 hours	4	20. 8	44. 5	65. 78	70. 92	24. 80	76. 47	83. 57	29. 16
50–75 hours	4	16. 7	60. 8	55. 30	61. 58	17. 95	64. 29	72. 57	21. 10
75–100 hours	4	13. 9	82. 0	35. 95	33. 02	10. 21	41. 79	38. 91	12. 00
100 hours and over	1	11. 0	107. 5	19. 40	30. 03	1. 83	22. 55	35. 39	2. 15
	1	8. 1	135. 9	18. 40	29. 96	3. 59	21. 39	35. 31	4. 22

The ordinates, at regular time-intervals, of the curves shown in Figures 33, 34, and 35, are shown in Table No. 121, following. In the case of the agar counts the ordinates given are computed from the formula of a curve fitted to the observations. In the cases of the gelatin count and *B. coli*, the curves shown are drawn simply by inspection, and the ordinates, taken graphically from these curves, serve merely to identify them and represent only a graphical smoothing and extension of the data given in Table No. 120.

TABLE No. 121.—*Ordinates of curves shown in Figures 33, 34, and 35, showing percentages of maximum bacterial count (y) in relation to time of flow from sewer outfalls (x)—Winter months, December to March, inclusive, 1914, 1915, 1916*

Time from sewer outlets (x)	Per cent of maximum numbers of bacteria (y)			Time from sewer outlets (x)	Per cent of maximum numbers of bacteria (y)		
	Gelatin	Agar	B. coli		Gelatin	Agar	B. coli
0 hours	89. 5	85. 5	97. 9	125 hours	30. 2	21. 4	5. 2
5 hours	96. 7	92. 1	99. 9	150 hours	25. 4	15. 8	3. 3
10 hours	98. 9	96. 1	95. 2	175 hours	22. 2	12. 2	2. 4
15 hours	99. 8	99. 1	87. 0	200 hours	20. 3	9. 8	2. 0
20 hours	100. 0	100. 1	75. 0	225 hours	19. 1	8. 1	1. 7
30 hours	97. 2	96. 5	52. 1	250 hours	18. 1	6. 9	1. 5
40 hours	89. 6	86. 8	36. 3	275 hours	17. 3	6. 0	1. 3
50 hours	79. 8	74. 3	27. 0	300 hours	16. 8	5. 2	1. 3
60 hours	68. 0	62. 1	20. 5	325 hours	16. 3	4. 7	1. 3
70 hours	57. 5	51. 9	15. 8	350 hours	16. 0	4. 2	1. 3
80 hours	49. 5	43. 2	12. 4	375 hours	15. 9	3. 8	1. 2
90 hours	43. 4	36. 3	10. 0	400 hours	15. 6	3. 5	1. 2
100 hours	38. 3	30. 8	8. 4				

NOTE.—Ordinates for the curve relating to agar counts computed from formula of fitted curve

$$y=\frac{1.28277}{1-(0.00347x+0.9850)\,10^{-0.003292x}}$$

Ordinates for gelatin count and *B. coli* curves determined graphically from curves fitted to observations simply by inspection and extrapolated.

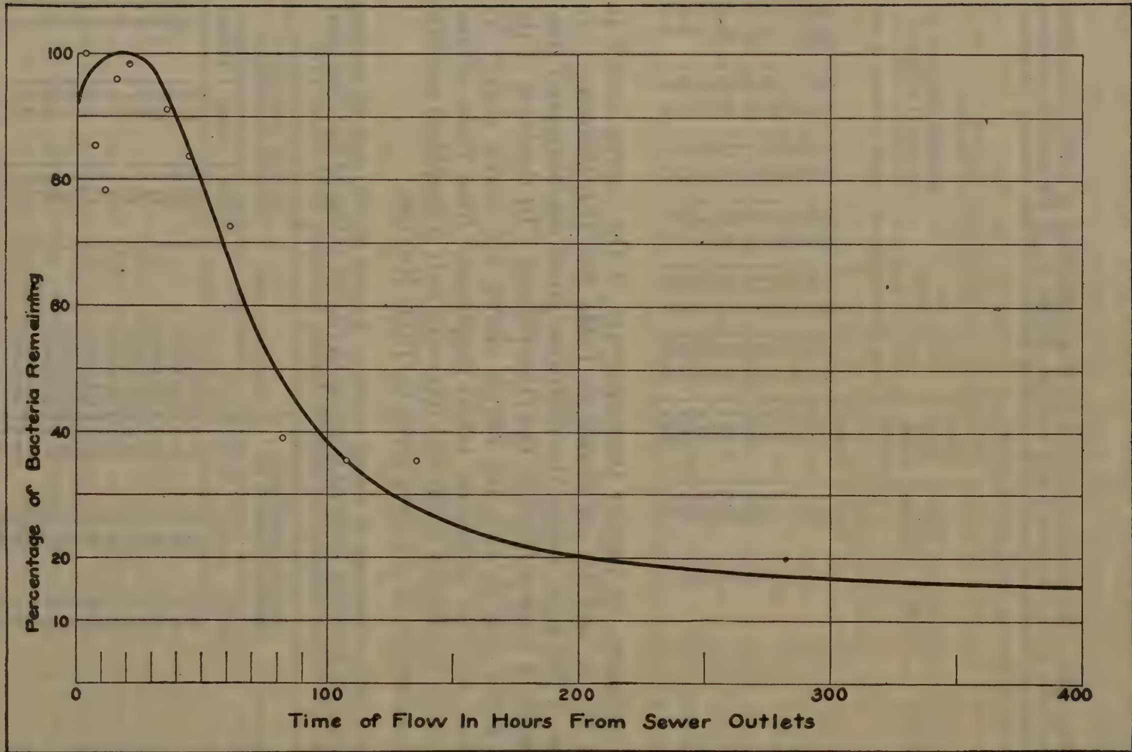

FIG. 33.—Bacterial purification in the Ohio River between Cincinnati and Louisville, in relation to time of flow from sewer outfalls of Cincinnati metropolitan district

Gelatin counts: Winter months, December–March, 1914, 1915, and 1916.
Percentages which the bacteria remaining at any time are of the numbers observed in the zone of maximum pollution.
Points (o) indicate actual observations (Table No. 120).
Ordinates of curve from Table No. 121.

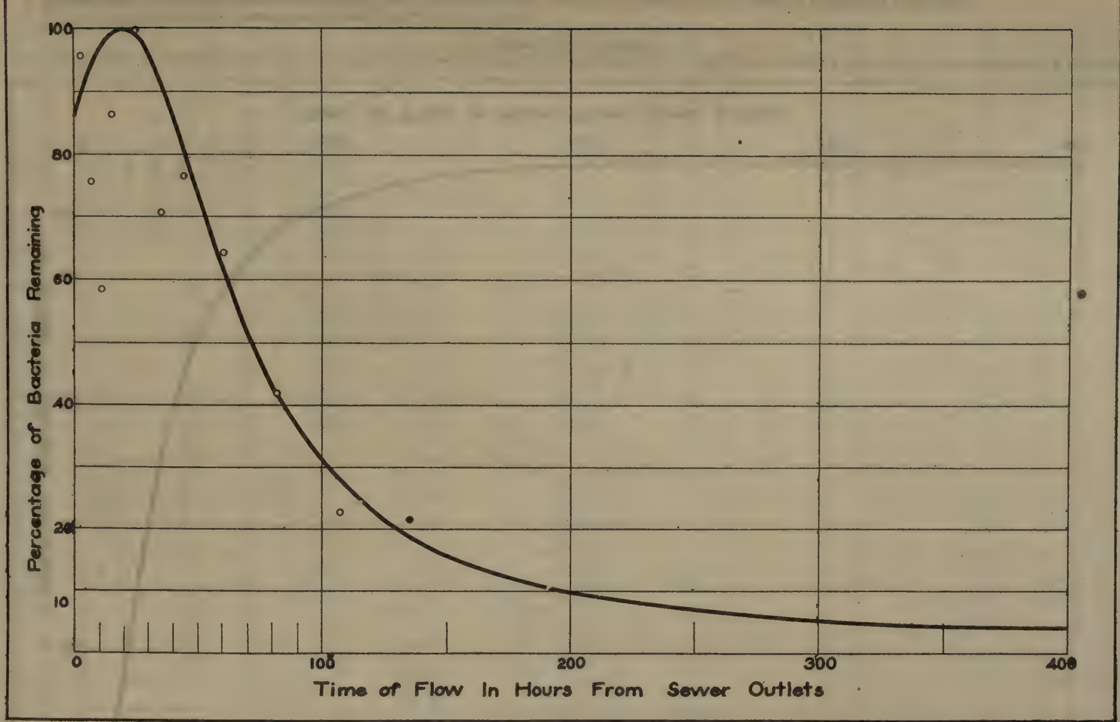

FIG. 34.—Bacterial purification in the Ohio River between Cincinnati and Louisville, in relation to time of flow from sewer outfalls of Cincinnati metropolitan district

Agar counts: Winter months, December–March, 1914, 1915, and 1916.
Percentages which the bacteria remaining at any time are of the numbers observed in the zone of maximum pollution.
Points (o) indicate actual observations (Table No. 120).
Ordinates of curve from Table No. 121.

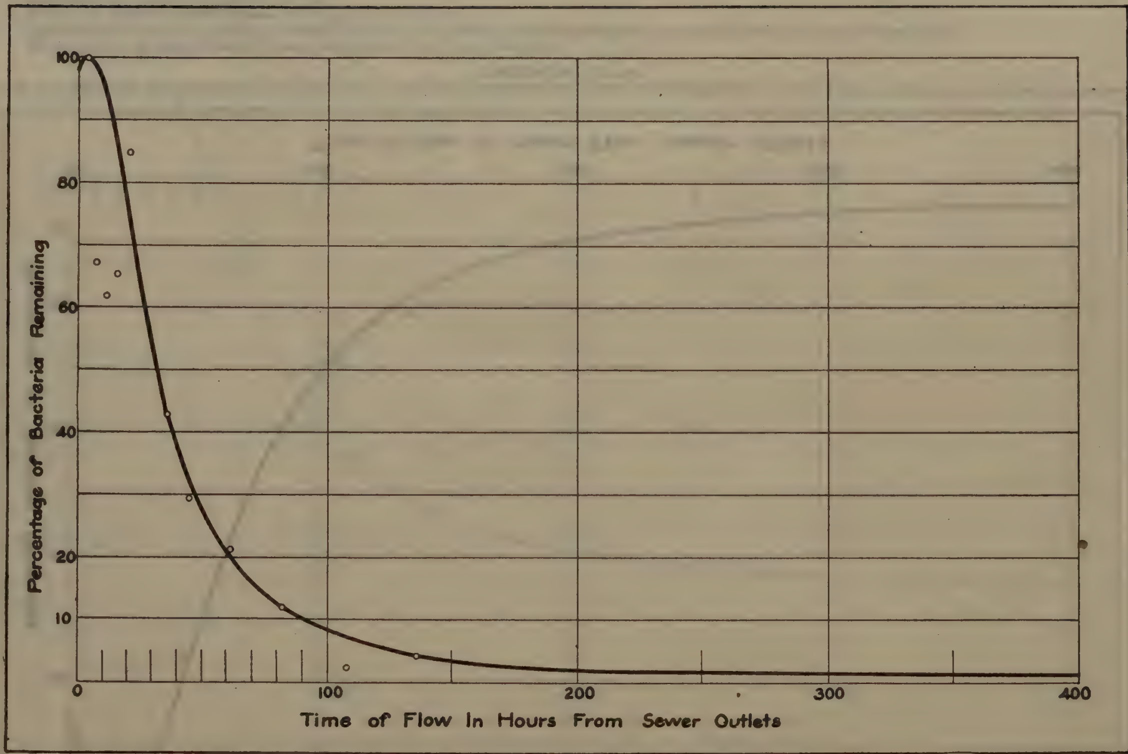

FIG. 35.—Bacterial purification in the Ohio River between Cincinnati and Louisville, in relation to time of flow from sewer outfalls of Cincinnat metropolitan district

B. coli: Winter months, December–March, 1914, 1915, and 1916.
Percentages which the bacteria remaining at any time are of the numbers observed in the zone of maximum pollution.
Points (o) indicate actual observations (Table No. 120).
Ordinates of curve from Table No. 121.

Interpreted literally, these figures would indicate that during the winter months the bacterial count in the Ohio River below Cincinnati tends, as in the summer months, to increase to a maximum, which is quite indefinite, but appears to occur, in the gelatin and agar counts, at about 20 hours below the sewer outlets, and in the *B. coli* at about 10 hours. From this point the tendency is toward a decrease, following roughly the paths indicated by the curves.

It is not considered, however, that such a literal interpretation is warranted, for, in the first place, that portion of the curves within about 40 hours is not in any sense definitely fixed by the observations and is largely hypothetical. Moreover, the data for the winter months, as given in Table No. 114, when examined in detail, do not show a consistent tendency to follow the courses indicated by these curves, except in one respect, namely, a fairly consistent decrease in counts after intervals exceeding 50 hours.

SUMMARY

Summarizing the changes in the bacterial content of the Ohio River from Cincinnati to Louisville, in relation to time of flow from the sewer outfalls of Cincinnati:

(1) During the seasonal period from April to November the number of bacteria, as indicated by agar and gelatin plate counts and by *B. coli* determinations, tends first to increase to a maximum which occurs at about 10 hours below the sewer outlets for the *B. coli* group, about 12.5 hours for the agar count, and about 15 hours for the gelatin count.

(2) Since this apparent increase may possibly be due entirely to sampling errors at the upper sampling stations, no definite biological significance can be attached to it.

(3) Beyond this observed maximum—that is, at times exceeding 10 to 15 hours from the sewer outfalls—the numbers of bacteria decrease regularly and rapidly, the rate of decrease being highest in the *B. coli* group, next in the agar count group, and least in the gelatin count group.

(4) Attempts to fit the observations to definitely formulated curves of the type:

$$y = \frac{b}{1 + (cx + d)e^{ax}}$$

have not been altogether successful; and, though it seems probable that better fits could be obtained, the attempt has not been pursued, because of the complexity of the formulae and because there is doubt as to whether the "crested" shape of the curve represents a biological phenomenon or merely a sampling error.

(5) The rates of decrease beyond the maximum are reasonably well defined in an empirical way by inspection curves fitted to the data up to the limit of the observations (about 500 hours).

(6) During the winter months the observations at times less than 50 hours from the sewer outlets are so irregular that their significance is altogether uncertain, but the few observations made at longer time intervals show a definite and orderly decrease in agar count, gelatin count and *B. coli* groups, similar to that observed in the summer months but at less rapid rates.

(7) In winter, as in summer, the rate of decrease is highest in the *B. coli* group, next highest in the agar count, and least in the gelatin count group.

BACTERIAL DECREASE BETWEEN CINCINNATI AND LOUISVILLE IN RELATION TO TIME OF FLOW FROM THE ZONE OF OBSERVED MAXIMUM COUNTS

The foregoing discussion of curves representing the changes in bacterial content of the river in relation to time of flow from an origin taken at the zone in which the sewage enters the river, leads finally to the conclusion that the only portion of these curves which is definitely significant is the descending limb, representing the rate of decrease after a maximum count has been reached. The further study will therefore be limited to the rate of decrease from this maximum as an origin.

The justification for this limitation is:

(1) That the primary increase from the uppermost sampling station to the maximum may possibly be only the result of sampling errors, in which case all observations upstream from the maximum must be considered erroneous.

(2) That the primary increase, even if it be a true and characteristic biological phenomenon, cannot be followed with any certainty nor measured with any degree of precision from the data at hand. At best it can merely be stated that in this particular river stretch the highest count would ordinarily be observed at a section which corresponds usually to a time interval of 10–15 hours below the sewer outlets.

(3) That the bacteriological phenomenon which is of real importance from the viewpoint of the sanitarian is the eventual decrease in numbers.

(4) That the simplest method which serves accurately to describe and measure this decrease serves all practical purposes.

In Table No. 122 the agar, gelatin, and *B. coli* counts, which have been previously shown in Table No. 114, are retabulated, excluding all observations upstream from the section at which the maximum count occurs in each gage height series. The time-intervals to successive downstream stations are then reckoned from the section at which the maximum is observed. The bacteria in this table are expressed in terms of "quantity units;" that is, the numbers per cubic centimeter as shown in Table No. 114, have been weighted by the corresponding discharges. This has been done, as previously explained, (p. 282) in order to eliminate the effect of varying dilutions. It will be noted, for example, that the "quantity units" (in thousands) at the origin vary only from 4,219 to 1,055, whereas the actual counts at these sections vary from 352,000 to 2,770 per cubic centimeter. It would answer the same purpose and give substantially the same result to express all counts in this table, as percentage of the maximum in the respective gage height series as in Table No. 115; but it has seemed preferable in this case to follow the more direct method of using the actual data in quantity units rather than ratios.

TABLE No. 122.—*Summary of bacteriological observations at all sampling stations between Cincinnati and Louisville during the months April to November, 1914, 1915, and 1916, grouped according to gage heights on dates of sampling, with corresponding mean times of flow from the section showing the maximum bacterial count to each sampling station below*

[Results expressed in thousand quantity units]

AGAR COUNTS

Mean gage-height, feet	Station 475		Station 482		Station 488		Station 492		Station 543		Station 598	
	Time, hours from maximum	Bacteria, thousand quantity units	Time, hours from maximum	Bacteria, thousand quantity units	Time, hours from maximum	Bacteria, thousand quantity units	Time, hours from maximum	Bacteria, thousand quantity units	Time, hours from maximum	Bacteria, thousand quantity units	Time, hours from maximum	Bacteria, thousand quantity units
1.3	0	2,538	28.7	342	38.9	242	43.5	236	172	13.7	475	1.49
2.5	0	4,219	21.7	829	29.8	806	33.9	713	131	15.1	301	2.72
3.4	0	3,616	17.7	656	24.9	550	28.6	570	111	39.0	247	3.93
4.4	0	1,967	14.9	1,771	21.4	1,280	24.8	1,241	95.7	122	209	1.06
5.3			0	2,590	6.0	1,551	9.2	1,052	71.4	219	172	16.1
6.5			0	3,437	5.4	1,907	8.3	1,187	61.7	162	147	24.9
7.5			0	2,327	4.9	2,292	7.6	1,807	54.9	432	131	37.0
8.5					0	3,947	2.6	2,846	44.9	627	114	48.5
9.5					0	3,203	2.4	2,879	40.6	772	103	104
10.8							0	3,513	33.6	* 123	88.7	114
12.8							0	2,820	28.8	1,835	74.6	271
14.8							0	2,739	25.9	566	64.2	338
17.1							0	4,201	23.5	2,137	55.1	527
18.9									0	2,124	27.7	477
22.1							0	1,866	20.0	1,194	43.4	712
26.9									0	1,587	19.6	746
36.3							0	1,055	15.1	798	32.3	643
43.5							0	1,381	12.5	1,065	28.3	873

* This figure, being irregular and based upon a small number of observations, is omitted in computing averages in Table 123

TABLE No. 122.—*Summary of bacteriological observations at all sampling stations between Cincinnati and Louisville during the months of April to November, 1914, 1915, and 1916, grouped according to gage heights on dates of sampling, with corresponding mean times of flow from the section showing the maximum bacterial count to each sampling station below*—Continued

GELATIN COUNTS

Mean gage-height, feet	Station 475		Station 482		Station 488		Station 492		Station 543		Station 598	
	Time, hours from maximum	Bacteria, thousand quantity units	Time, hours from maximum	Bacteria, thousand quantity units	Time, hours from maximum	Bacteria, thousand quantity units	Time, hours from maximum	Bacteria, thousand quantity units	Time, hours from maximum	Bacteria, thousand quantity units	Time, hours from maximum	Bacteria, thousand quantity units
1.3	0	1, 642	28. 7	341	38. 9	354	43. 5	371	172	15. 8	475	1. 48
2.5	0	3, 046	21. 7	1, 083	29. 8	1, 051	33. 9	937	131	15. 6	301	2. 88
3.4	0	2, 692	17. 7	767	24. 9	868	28. 6	950	111	74. 7	247	9. 29
4.4	0	1, 843	14. 9	1, 711	21. 4	1, 534	24. 8	1, 701	95. 7	132	209	15. 8
5.3			0	2, 546	6. 0	1, 730	9. 2	1, 392	71. 9	429	172	22. 4
6.5			0	2, 623	5. 4	1, 758	8. 3	1, 031	61. 7	113	147	31. 3
7.5					0	2, 303	2. 7	1, 857	50. 0	519	126	59. 5
8.5							0	5, 057	42. 3	691	111	53. 7
9.5					0	3, 248	2. 4	2, 664	40. 6	786	103	106
10.8							0	3, 461	33. 6	1, 600	88. 7	147
12.8							0	3, 175	28. 8	3, 025	74. 6	326
14.8							0	2, 532	25. 9	1, 447	64. 2	454
17.1							0	4, 885	23. 5	3, 564	55. 1	729
18.9									0	2, 500	27. 7	827
22.1							0	2, 409	20. 0	1, 895	43. 4	1, 637
26.9									0	2, 841	19. 6	1, 490
36.3							0	3, 355	15. 1	3, 212	32. 3	1, 874
43.5											0	6, 059
B. COLI												
1.3	0	49. 75	28. 7	6. 02	38. 9	4. 27	43. 5	3. 87	172	0. 142	475	0. 0269
2.5	0	48. 07	21. 7	28. 24	29. 8	14. 44	33. 9	8. 54	131	. 336	301	. 0696
3.4	0	113. 67	17. 7	20. 15	24. 9	20. 89	28. 6	18. 75	111	. 129	247	. 164
4.4	0	69. 33	14. 9	29. 60	21. 4	34. 39	24. 8	25. 19	95. 7	8. 874	209	. 0700
5.3			0	57. 49	6. 0	35. 70	9. 2	35. 95	71. 9	4. 080	172	. 304
6.5			0	70. 95	5. 4	52. 47	8. 3	43. 55	61. 7	12. 376	147	. 0881
7.5			0	68. 83	4. 9	48. 60	7. 6	40. 10	54. 9	19. 339	131	1. 043
8.5			0	94. 08	4. 5	73. 47	7. 1	32. 94	49. 4	12. 220	118	. 7934
9.5							0	80. 77	38. 2	7. 796	101	. 1494
10.8					0	66. 80	2. 3	65. 60	35. 9	20. 864	91. 0	1. 806
12.8							0	64. 48	28. 8	25. 740	74. 6	4. 518
14.8							0	126. 87	25. 9	15. 839	64. 2	7. 075
17.1							0	130. 41	23. 5	33. 499	55. 1	7. 487
18.9					0	89. 86	1. 6	36. 06	23. 6	40. 038	51. 3	9. 251
22.1							0	47. 37	20. 0	25. 230	43. 4	1. 697
26.9	0	39. 81	2. 8	22. 59	4. 9	30. 24	6. 3	19. 08			43. 9	13. 340
36.3			0	47. 57	1. 8	18. 45	3. 1	25. 95	18. 2	20. 180	35. 4	14. 819
43.5							0	107. 78	13. 5	27. 944	28. 8	9. 980

In two series of observations in this table, at gage heights 18.9 and 36.3 feet, the origin from which time is reckoned for the agar counts is not the true maximum, but a section farther downstream. This is done on account of irregularities in the sequence of counts. Thus, at gauge height 18.9 the agar counts recorded were:

At station 475	25, 962
At station 482	17, 918
At station 488	16, 969
At station 492	15, 272
At station 543	18, 441
At station 598	4, 141

Since the count first decreases, to station 492, then increases at station 543, the irregular counts above the latter station have been disregarded as being probably affected by some rather unusual error, and the origin has been taken at station 543. Likewise at gage height 36.3 feet, the highest count observed was 5,312 per cubic centimeter at station 482, decreasing to 2,754 at station 488, then increasing again to 3,661 at station 492. Therefore in this series station 492 is taken as the origin, instead of station 482.

Extent and rates of decrease in summer months.—The agar count data from Table No. 122, regrouped according to time intervals of flow from the maximum, are shown in detail in Table No. 123. From this table it may be seen that, with some exceptions, the bacteria decrease quite regularly as the time intervals increase, so that the numbers which fall within any given time interval are generally of the same order of magnitude, and are quite fairly represented by their means.

TABLE No. 123.—*Data from Table No. 122 regrouped according to time intervals of flow from sampling station at which maximum count was observed, agar counts, quantity units, months April to November*

Sampling station	Gage height, feet	Time of flow from maximum, hours	Bacteria, thousand quantity units
ORIGIN, MAXIMUM			
475	1.3	0	2,538
475	2.5	0	4,219
475	3.4	0	3,616
475	4.4	0	1,967
482	5.3	0	2,590
482	6.5	0	3,437
482	7.5	0	2,327
488	8.5	0	3,947
488	9.5	0	3,203
492	10.8	0	3,513
492	12.8	0	2,820
492	14.8	0	2,738
492	17.1	0	4.201
492	22.1	0	1,866
492	36.3	0	1,055
492	43.5	0	1,381
543	18.9	0	2,124
543	26.9	0	1,587
Mean			2,729
TIME, 0–5 HOURS			
488	7.5	4.9	2,292
492	9.5	2.4	2,879
492	8.5	2.6	2,846
Mean		3.3	2,672
TIME, 5–10 HOURS			
488	6.5	5.4	1,907
488	5.3	6.0	1,551
492	7.5	7.6	1,807
492	6.5	8.3	1,182
492	5.3	9.2	1,052
Mean		7.3	1,500
TIME, 10–15 HOURS			
482	4.4	14.9	1,771
543	43.5	12.5	1,065
Mean		13.7	1,418
TIME, 15–20 HOURS			
482	3.4	17.7	656
543	36.3	15.1	798
598	26.9	19.6	746
Mean		17.5	733
TIME, 20–25 HOURS			
482	2.5	21.7	829
488	4.4	21.4	1,280
488	3.4	24.9	550
492	4.4	24.8	1,241
543	22.1	20.0	1,194
	17.1	23.5	2,137
Mean		22.7	1,205
TIME, 25–30 HOURS			
482	1.3	28.7	342
488	2.5	29.8	806
492	3.4	28.6	570
543	14.8	25.9	566
543	12.8	28.8	1,835
598	43.5	28.3	873
598	18.9	27.7	477
Mean		28.2	781

TABLE No. 123.—*Data from Table No. 122 regrouped according to time intervals of flow from sampling station at which maximum count was observed, agar counts, quantity units, months April to November*—Continued

Sampling station	Gage height, feet	Time of flow from maximum, hours	Bacteria, thousand quantity units
TIME, 30-40 HOURS			
488	1.3	38.9	242
492	2.5	33.9	713
598	36.3	32.3	643
Mean		35.0	533
TIME, 40-50 HOURS			
492	1.3	43.5	236
543	9.5	40.6	772
543	8.5	44.9	627
598	22.1	43.4	712
Mean		43.1	587
TIME, 50-75 HOURS			
543	7.5	54.9	432
543	6.5	61.7	162
543	5.3	71.9	219
598	17.1	55.1	527
598	14.8	64.2	338
598	12.8	74.6	271
Mean		62.7	324
TIME, 75-100 HOURS			
543	4.4	95.7	122
598	10.8	88.7	114
Mean		92.2	118
TIME, 100-125 HOURS			
543	3.4	111	39.0
598	9.5	103	104.2
598	8.5	114	48.5
Mean		109	63.9
TIME, 125-150 HOURS			
543	2.5	131	15.1
598	7.5	131	37.0
598	6.5	147	25.0
Mean		136	25.7
TIME 150-200 HOURS			
543	1.3	172	13.7
598	5.3	172	16.1
Mean		172	14.9
TIMES, OVER 200 HOURS			
598	4.4	209	10.63
598	3.4	247	3.93
598	2.5	301	2.72
598	1.3	475	1.49

The data from this table are summarized in Table No. 124, which shows:

In column (1) the time intervals of flow from the maximum within which observations have been grouped for averaging.

In column (2) the mean of the recorded times falling within each interval.

In column (3) the mean numbers of bacteria, in thousands of quantity units (numbers per cubic centimeter × discharge, in second-feet, divided by 1,000,000), as shown by observations falling within the designated limits of time from the maximum.

In column (4) the percentages which the bacteria remaining in each time period are of the numbers (quantity units) observed at the maximum.

Corresponding data are given in columns (5) to (10), inclusive, for gelatin counts and *B. coli*, similarly grouped.[26]

[26] The mean times of flow in corresponding time periods are not necessarily identical, since the maximum of agar, gelatin, and *B. coli* counts does not always occur at the same section.

TABLE No. 124.—*Average numbers of bacteria, in quantity units, at section below Cincinnati showing maximum count (origin) and at indicated times of flow below this maximum, April to November, inclusive, 1914, 1915, 1916*

Time intervals from maximum	Agar counts			Gelatin counts			B. coli		
	Mean time from maximum hours	Bacteria remaining		Mean time from maximum hours	Bacteria remaining		Mean time from maximum hours	Bacteria remaining	
		Quantity units, thousands[1]	Per cent of maximum		Quantity units, thousands[1]	Per cent of maximum		Quantity units, thousands[1]	Per cent of maximum
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Origin	0	2, 729	100. 00	0	2, 951	100. 00	0	76. 32	100. 00
Under 5 hours	3. 3	2, 672	97. 91	2. 6	2, 260	76. 58	3. 2	40. 12	52. 56
5–10 hours	7. 3	1, 500	54. 96	7. 2	1, 478	50. 08	7. 1	37. 11	48. 62
10–15 hours	13. 7	1, 418	51. 96	14. 9	1, 711	57. 98	14. 2	28. 77	37. 69
15–20 hours	17. 5	733	26. 86	17. 4	1, 823	61. 78	17. 9	20. 16	26. 41
20–25 hours	22. 7	1, 205	43. 79	22. 7	1, 774	60. 12	22. 8	29. 64	38. 83
25–30 hours	28. 2	781	28. 62	28. 2	1, 273	43. 14	28. 3	15. 13	19. 82
30–40 hours	35. 0	533	19. 58	34. 7	1, 191	40. 36	36. 5	11. 26	14. 75
40–50 hours	43. 1	587	21. 51	42. 5	871	29. 51	45. 0	7. 78	10. 20
50–75 hours	63. 7	324	11. 89	62. 9	428	14. 51	61. 9	9. 16	12. 00
75–100 hours	92. 2	118	6. 58	92. 2	139	4. 71	93. 4	5. 34	9. 00
100–125 hours	109	63. 9	2. 34	108	78. 1	2. 65	110	. 357	. 467
125–150 hours	136	25. 7	. 941	135	35. 5	1. 20	136	. 489	. 640
150–200 hours	172	14. 9	. 546	172	19. 1	. 647	172	. 223	. 292
Over 200 hours	209	10. 63	. 389	209	15. 8	. 535	209	. 070	. 092
	247	3. 93	. 144	247	9. 29	. 315	247	. 164	. 215
	301	2. 72	. 100	301	2. 88	. 098	301	. 070	. 091
	475	1. 49	. 055	475	1. 48	. 050	475	. 027	. 035

[1] Bacteria per cubic centimeter × discharge in second-feet ÷ 1,000,000.

Inspection of this table shows that the decrease, as indicated by the percentages of bacteria remaining at successive time intervals, though showing some irregularities, is on the whole remarkably regular and orderly. The relation of the bacterial decrease to time is better shown, however, when the percentages of bacteria remaining at each time are plotted as ordinates on a logarithmic scale (which is equivalent to plotting their logarithms on an arithmetic scale), with corresponding times of flow from the maximum plotted as abscissæ on an arithmetic scale, as in Figure 36, which serves also to illustrate the method used in formulating the relation of decrease to time.

Formulation of curves of bacterial decrease.—It is apparent from this figure that the trend of the observations in the whole series can be represented best by a curved line, of progressively diminishing slope, implying that the rate of decrease diminishes progressively with increasing time. However, the observations within any limited period of time, as, for example, within the first 60 hours; from 60 to 150 hours; and from 200 to 500 hours, lie more or less regularly along straight lines, so that the curve as a whole may be considered as a composite of a series of straight lines of diminishing slopes.

The simplest assumption for formulation of the curve from this point of view is to consider it as made up of only two such straight lines, tangent to its proximal and distal portions.

Since the ordinates are logarithmic, any straight line is represented by the equation:

$$\log_{10}y = \log_{10}a - bx \tag{1}$$

which may also be written:

$$y = a\ (10^{-bx}) \tag{2}$$

Consequently, the curve made up of two component straight lines, having constants (a) (b) and (c) (d), respectively, will be represented by the equation:

$$y = a\ (10^{-bx}) + c\ (10^{-dx}) \tag{3}$$

In resolving the curve into two component straight lines the steps in the procedure followed were:

(1) A smooth curve was carefully drawn by inspection through the points defined by the observations.

(2) A straight line was then drawn tangent to the lower extremity of the curve.

(3) The constant (c) in the equation of this line $y = c\ (10^{-dx})$ was then determined graphically by taking $x = 0$, when the equation becomes $y = c$.

(4) The constant (d) was then determined by substituting in the equation; $\log y = \log c - dx$ any convenient coordinate values of (x) and (y) as determined graphically.

(5) In the equation $y = a\ (10^{-bx}) + c\ (10^{-dx})$, when $x = 0$, $y = a + c = 100$ (per cent): hence $a = 100 - c$.

(6) The value of the constant (b) was determined by substituting, in equation (3), the previously determined values of (a), (c), and (d) with any convenient coordinates values of (x) and (y) determined graphically, verifying the result by substituting other values of (x) and (y).[27]

The values of the constants in the equation:

$$y = a\ (10^{-bx}) + c\ (10^{-dx}) \tag{3}$$

as thus determined for the agar count, gelatin count and *B. coli* observations, and the ordinates corresponding to graduated time-intervals (x) are shown in Table No. 125. The curves shown in Figures 36 to 41, inclusive, are drawn from these coordinates, and the actual observations given in Table No. 124 are plotted as points, in order to indicate their consistency and their fit to the curves.

[27] The adjustment of the values of these constants by the conventional method of least squares, which suggests itself, is not practicable because the excessive weight given by this method to observations in the upper section of the curve distorts the result giving a curve which entirely fails to fit the actual observations.

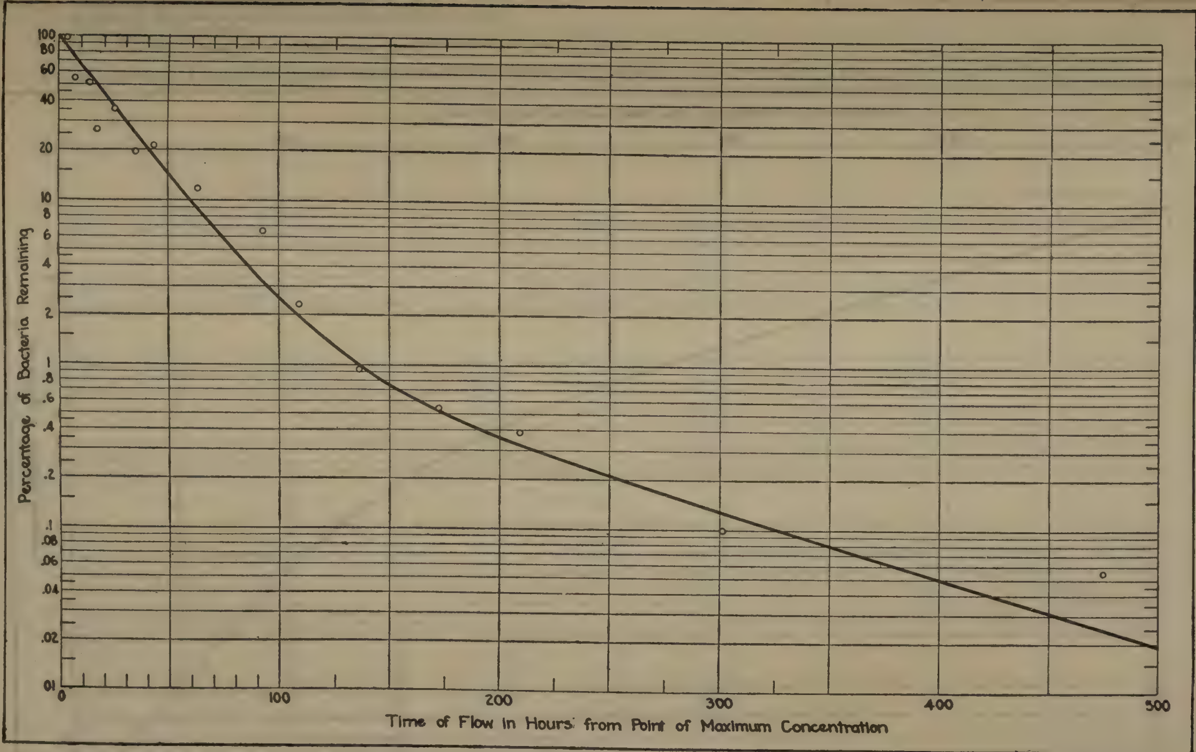

FIG. 36.—Bacterial purification in Ohio River between Cincinnati and Louisville in relation to time of flow from zone of maximum pollution

Agar counts: Summer months, April–November, 1914, 1915, and 1916.
Logarithmic ordinates.
Points (o) indicate actual observations (Table No. 124).
Ordinates of curves from Table No. 125.

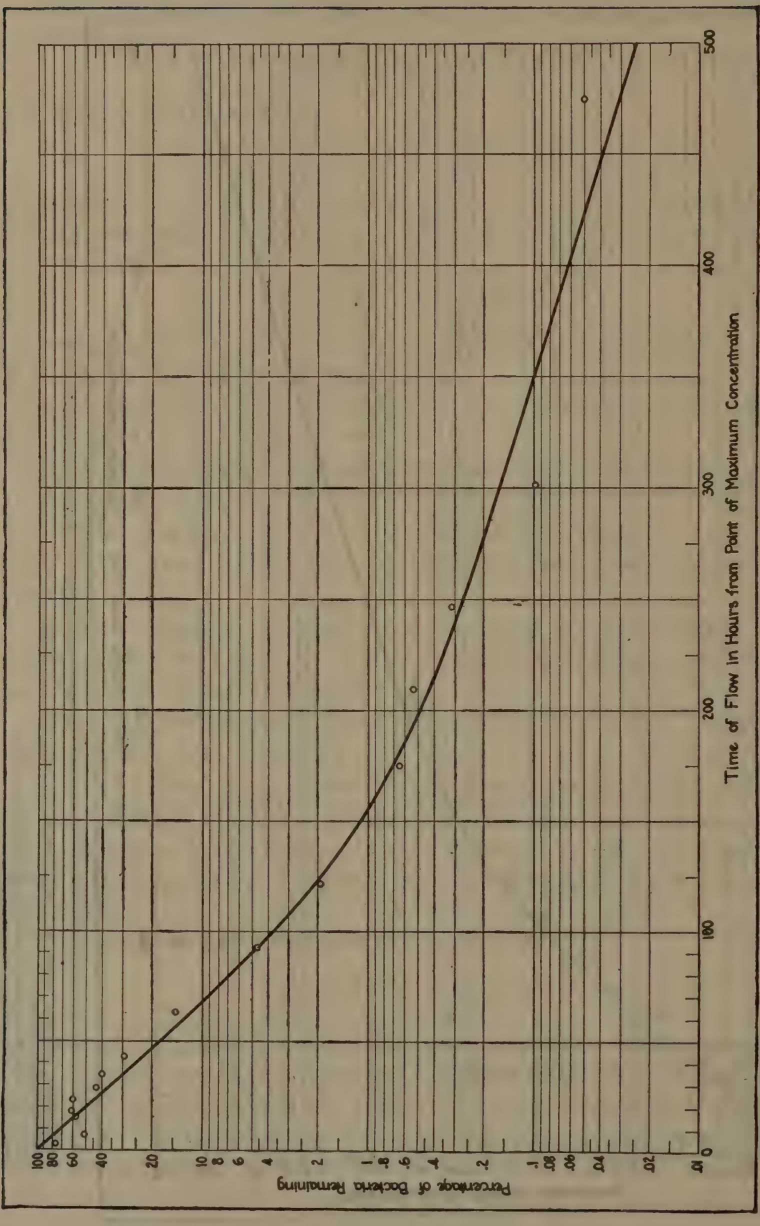

FIG. 37.—Bacterial purification in Ohio River between Cincinnati and Louisville in relation to time of flow from zone of maximum pollution

Gelatin counts: Summer months, April–November, 1914, 1915, and 1916.
Logarithmic ordinates.
Points (o) indicate actual observations (Table No. 124).
Ordinates of curve from Table No. 125.

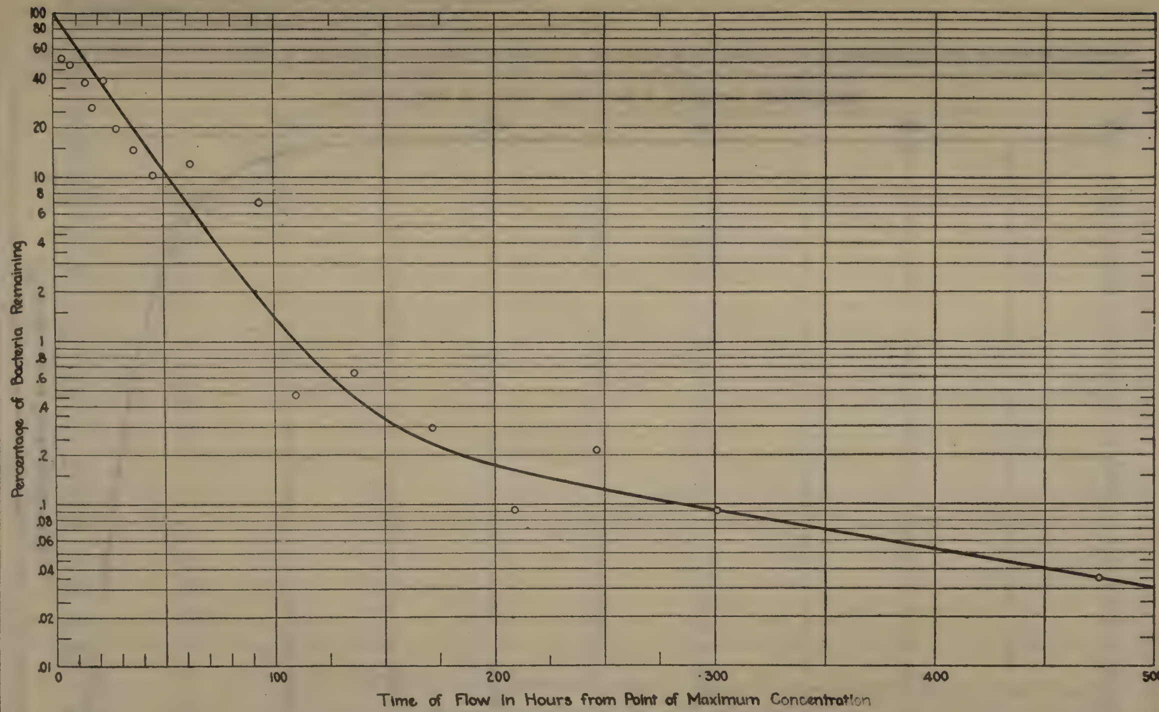

FIG. 38.—Bacterial purification in Ohio River between Cincinnati and Louisville in relation to time of flow from zone of maximum pollution

B. Coli: Summer months, April–November, 1914, 1915, and 1916.
Logarithmic ordinates.
Points (o) indicate actual observations (Table No. 124).
Ordinates of curve from Table No. 125.

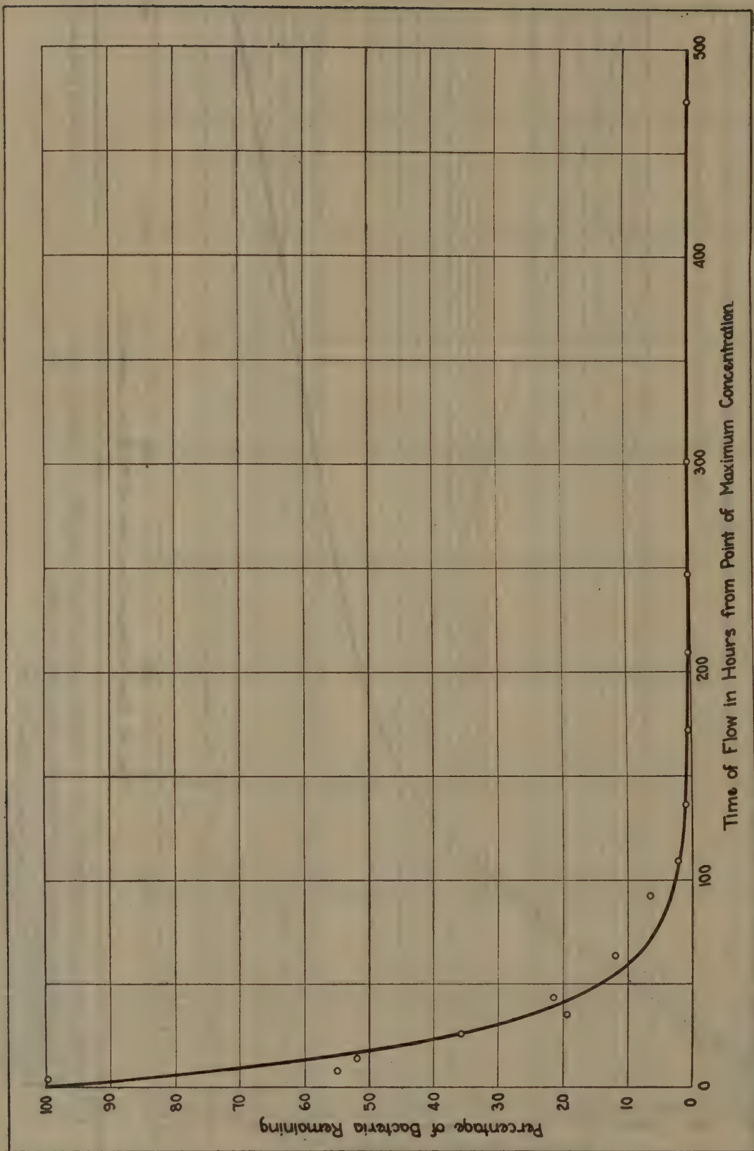

FIG. 39.—Bacterial purification in Ohio River between Cincinnati and Louisville in relation to time of flow from zone of maximum pollution.

Agar counts: Summer months, April-November, 1914, 1915, and 1916.
Simple ordinates.
(See fig. 36 for identical data drawn to logarithmic ordinates.)

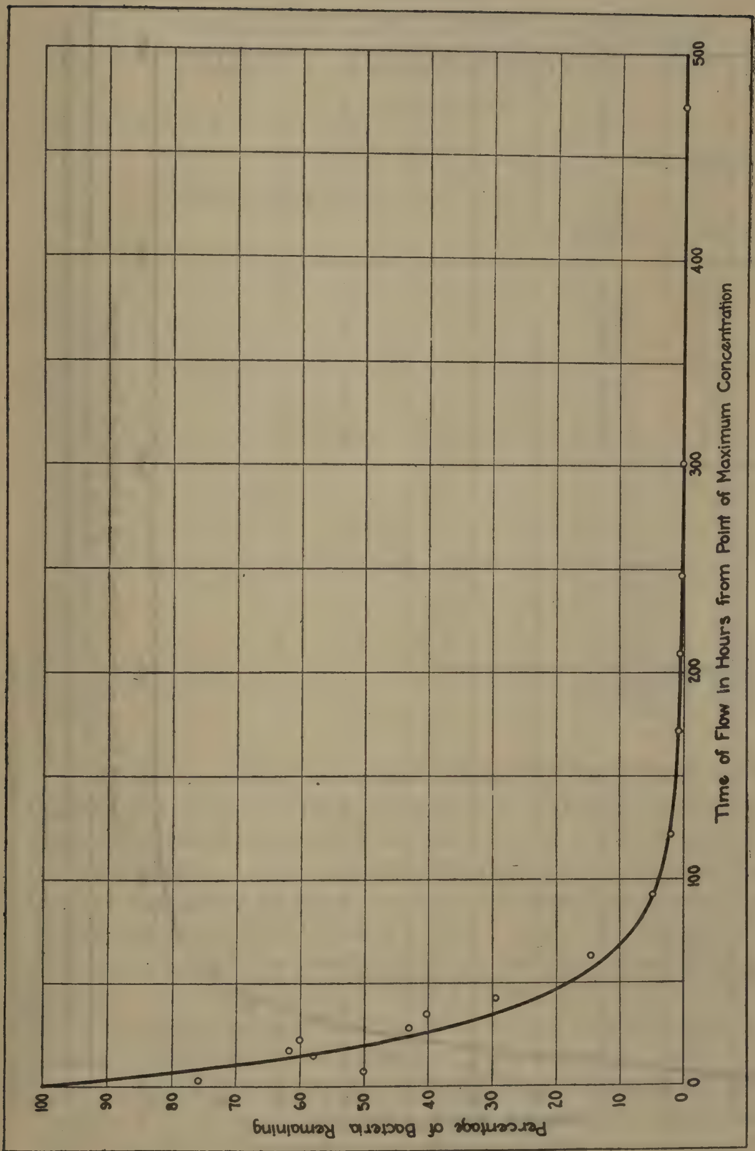

FIG. 40.—Bacterial purification in Ohio River between Cincinnati and Louisville in relation to time of flow from zone of maximum pollution

Gelatin counts: Summer months, April–November, 1914, 1915, and 1916.
Simple ordinates.
(See fig. 37 for identical data drawn to logarithmic ordinates.)

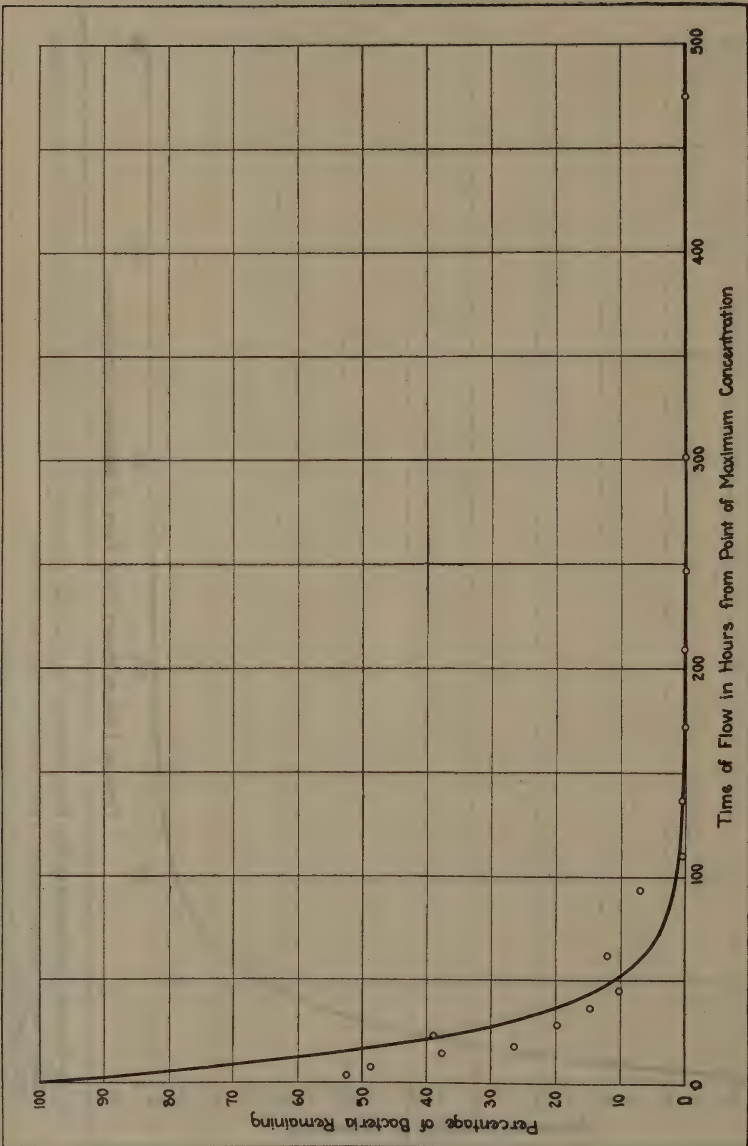

FIG. 41.—Bacterial purification in Ohio River between Cincinnati and Louisville in relation to time of flow from zone of maximum pollution

B. coli: Summer months, April-November, 1914, 1915, and 1916.
Simple ordinates.
(See fig. 38 for identical data drawn to logarithmic ordinates.)

TABLE No. 125.—*Formulae and coordinates of curves describing decrease in gelatin counts, agar counts, and B. coli, in relation to time of flow from zone of maximum pollution*

[Curves apply to river stretch from Cincinnati to Louisville and to the seasonal period April to November, inclusive]

FORMULAE

Gelatin counts: $y=97.2.(10^{-0.01568x})+2.8(10^{-0.004137x})$
Agar counts: $y=97.8.(10^{-0.01757x})+2.2(10^{-0.004109x})$
B. coli: $y=99.51.(10^{-0.0195x})+4.9(10^{-0.00242x})$

COORDINATES

Time of flow from maximum (x)	Percentage of bacteria remaining (y)		
	Gelatin count (y)	Agar count (y)	B. coli (y)
0 hour	100. 00	100. 00	100. 00
10 hours	70. 29	67. 26	63. 97
20 hours	49. 52	45. 37	40. 98
30 hours	35. 01	30. 71	26. 28
40 hours	24. 84	20. 90	16. 90
50 hours	17. 72	14. 31	10. 91
60 hours	12. 72	9. 879	7. 08
70 hours	9. 10	6. 894	4. 62
80 hours	6. 71	4. 876	3. 06
90 hours	4. 96	3. 504	2. 05
100 hours	3. 708	2. 565	1. 398
125 hours	1. 917	1. 296	. 607
150 hours	1. 103	. 759	. 330
175 hours	. 715	. 502	. 223
200 hours	. 488	. 362	. 173
225 hours	. 357	. 273	. 144
250 hours	. 270	. 211	. 123
275 hours	. 2087	. 164	. 106
300 hours	. 1628	. 1295	. 0921
350 hours	. 1001	. 0802	. 0697
400 hours	. 0620	. 0500	. 0528
450 hours	. 0385	. 0312	. 0399
500 hours	. 0239	. 0194	. 0302
600 hours	. 00923	. 00754	. 0173
700 hours	. 00356	. 00293	. 00991
800 hours	. 00138	. 00114	. 00568
900 hours	. 000530	. 000441	. 00326
1,000 hours	. 000204	. 000171	. 00186

It should be noted, as is best shown by the figures drawn with logarithmic ordinates, that the points to which the curves are fitted are rather widely scattered at times beyond 200 hours; also that the total number of observations represented by each of the points beyond 200 hours is much smaller than that represented by points within 200 hours (see Table No. 123), so that the distal sections of the curves are defined with much less certainty than their proximal sections. As regards the ordinates shown in Table No. 125, calculated for times beyond the range of actual observations, they can not be considered at all reliable. They represent only the values that would obtain if the rates of decrease indicated by the curves continued to be operative, but furnish no evidence that such is the case. In fact, it would seem probable that the rates of decrease diminish at long times more than is indicated by these curves.

The observations at the upper extremity of the curves, within about 50 hours from the maximum, are also quite irregular, but

those falling within a range of about 50 to 250 or 300 hours lie quite close to the curves. This, which is the most definite section of the curves, is probably also the most important; for a knowledge of the rate of purification in this river stretch is of value chiefly as indicating the extent of the protection which it affords to the water supply of Louisville, and during the greater part of the spring, summer, and autumn seasons the time of flow from Cincinnati to Louisville is between 50 and 300 hours.

Comparative rates of decrease in gelatin count, agar count, and B. coli groups.—Figure 42, in which are brought together the curves indicating the rates of decrease of the gelatin count, agar, and *B. coli* groups, indicates that up to about 400 hours the rate of decrease is highest in the *B. coli* and lowest in the gelatin count group. This is according to *a priori* expectation. The *B. coli* group, being made up more largely of organisms which are quite foreign to the environment found in a river, might be expected to die more rapidly than the group represented by the 20° gelatin count, which, presumably, comprises a somewhat larger proportion of organisms native to the soil; and the 37° agar count group would be expected to be intermediate between these two. Although the curves as formulated indicate a reversal of these relative rates beyond 400 hours, it is doubtful whether this is of any real significance, since, as already noted, the lower ends of the curves and their extensions are not definitely fixed by the few and scattered observations at times beyond 250–300 hours.

Extent and rates of decrease in winter months.—As has been previously noted, and as may be seen by reference to Table No. 114, the agar and gelatin counts during the winter months at gage heights over 25 feet showed no tendency to any decrease in the entire stretch from station 475 to 598, but rather a tendency to increase, so that the counts were generally higher at station 598 than at station 475 or at any intermediate station. This does not necessarily imply that the processes of natural purification were entirely inactive at such periods. It may perhaps signify merely that the processes were so retarded that the purification, if any, which took place within 50 hours or less was not sufficient to be definitely measurable, having due regard to the probable magnitude of the observational error; but since the winter observations at high river stages show *no decrease* it seems proper, in a study of the rates of purification in winter, to exclude them and to confine attention to observations at gage heights under 25 feet.

Again, as previously noted (see p. 295), the observations at stations 482 and 488 in winter, even within the lower range of gage heights, are entirely out of line with those at the other stations, so the general trend of the observations as a whole may be shown much more simply and perhaps as correctly by disregarding these two stations.

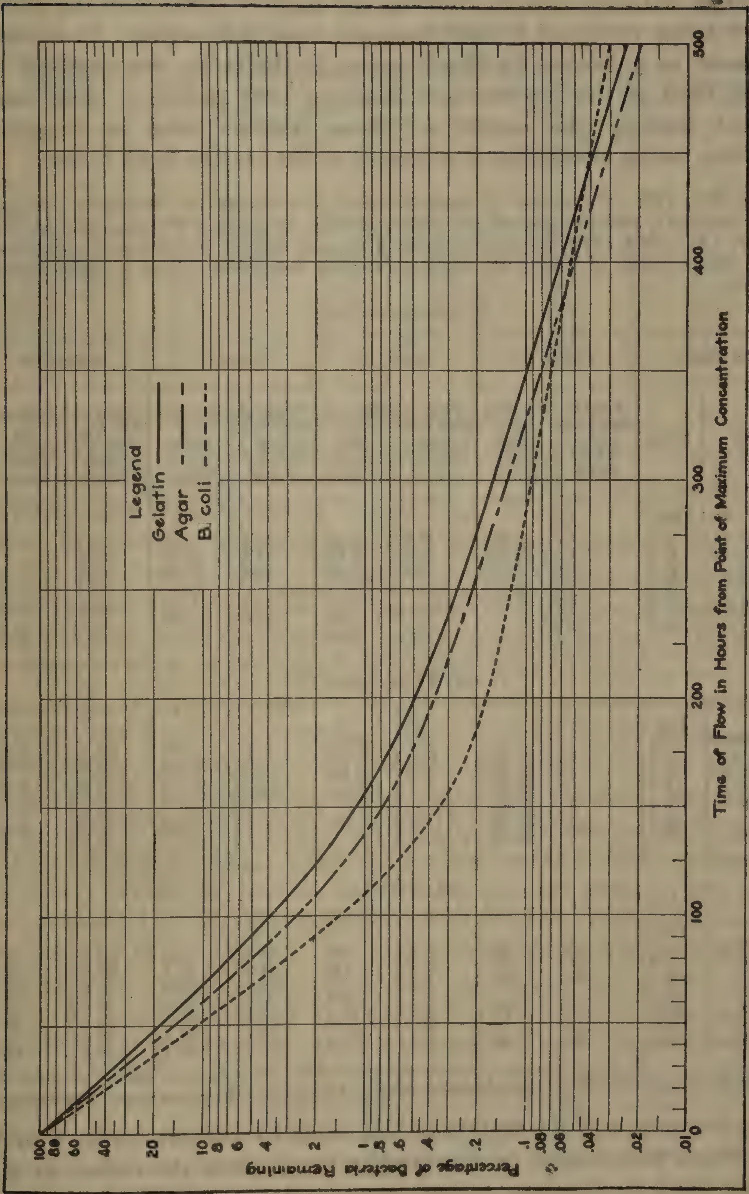

FIG. 42.—Comparison of rates of decrease in bacteria of gelatin count, agar count, and *B. coli* groups in Ohio River between Cincinnati and Louisville

Summer months: April–November, 1914, 1915, and 1916.
(Curves identical with those shown in figs. 36, 37, and 38, respectively.)

The agar counts, gelatin counts, and *B. coli* determinations at stations 475, 492, 543, and 598, as given in Table No. 114, are, therefore, summarized in Table No. 126, the series for each gage height beginning with the section showing the highest count, and the times of flow being reckoned in each instance from this origin. In several instances, as indicated by blank spaces in the table, observations at one or both of the intermediate stations (492 and 543) have been omitted because the counts at these stations were in irregular sequence, being lower than the counts at the station next below.

TABLE No. 126.—*Summary of bacteriological observations at sampling stations 475, 482, 488, and 492, during the winter months, January, February, and March, 1914, 1915, and 1916, grouped according to gage heights on dates of sampling, with mean times of flow from section showing maximum count to each station below*

Gage height		Station 475		Station 492		Station 543		Station 598	
Range	Mean	Time of flow from maximum, hours	Bacteria per cubic centimeter	Time of flow from maximum, hours	Bacteria per cubic centimeter	Time of flow from maximum, hours	Bacteria per cubic centimeter	Time of flow from maximum, hours	Bacteria per cubic centimeter
I. AGAR COUNTS									
	Feet								
Under 10 feet	8.1	0	3,881	14.8	3,462	59.3	1,165	131.3	715
10–12 feet	11.0	0	3,750	11.3	2,447	44.3	1,190	103.8	725
12–14 feet	13.1	0	2,780	9.8	1,716	38.3	1,229	83.3	783
14–16 feet	14.5	0	3,147		[1]		[1]	75.1	1,376
16–18 feet	17.0	0	2,781		[1]	31.6	1,646	63.6	1,305
18–20 feet	18.9			0	5,325	22.0	2,256	50.0	1,784
20–25 feet	22.6	0	2,917	6.7	2,689		[1]	49.7	2,453
II. GELATIN COUNTS									
	Feet								
Under 10 feet	8.1			0	17,912	44.5	7,771	116.5	5,367
10–12 feet	11.0	0	11,957	11.3	9,721	44.3	6,189	103.8	3,591
12–14 feet	13.1	0	13,095	9.8	7,861	38.3	4,883	83.3	3,953
14–16 feet	14.5	0	32,588	9.1	27,669	35.1	23,462	75.1	11,680
16–18 feet	17.0	0	12,501		[1]		[1]	63.6	8,119
18–20 feet	18.9	0	22,560	7.5	19,926	29.5	12,199	57.5	10,863
20–25 feet	22.6	0	22,829		[1]		[1]	49.7	20,511
III. B. COLI									
	Feet								
Under 10 feet	8.1	0	306	14.8	223	59.3	25.0	131.3	11.0
10–12 feet	11.0	0	465	11.3	143	44.3	53.5	103.8	8.5
12–14 feet	13.1	0	332	9.8	166	38.3	46.0	83.3	18.0
14–16 feet	14.5			0	260	26.0	40.0	66.0	39.0
16–18 feet	17.0	0	206	8.0	96.3	31.6	32.5	63.6	28.5
18–20 feet	18.9			0	87.5	22.0	70.0	50.0	35.4
20–25 feet	22.6	0	160	6.7	103.0	26.7	59.3	49.7	40.9

[1] Observations omitted because of their irregular sequence, falling below the counts farther downstream.

The conversion of the counts in this table to quantity units would serve no purpose except to obscure the trend, since the counts at all stations tend to increase rather than to decrease with increasing discharge. Therefore, for averaging the observations in similar time intervals, the actual counts (numbers per cubic centimeter) have been used. The results are summarized in Table No. 127.

TABLE No. 127.—*Average numbers of bacteria (per cubic centimeter) at section below Cincinnati showing maximum count (origin) and at indicated times of flow below this maximum, omitting observations from stations Nos. 482 and 488—Winter months, December to March, inclusive, 1914, 1915, 1916*

Time intervals from maximum	Agar counts			Gelatin counts			B. coli		
	Mean time from maximum	Bacteria per cubic centimeter		Mean time from maximum	Bacteria per cubic centimeter		Mean time from maximum	Bacteria per cubic centimeter	
		Number	Per cent of maximum		Number	Per cent of maximum		Number	Per cent of maximum
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Origin	0	3, 511	100. 0	0	19, 063	100. 0	0	260	100. 0
5–10 hours	8. 2	2, 202	62. 7	8. 8	18, 485	97. 0	8. 2	122	46. 9
10–15 hours	13. 0	2, 954	84. 1	11. 3	9, 721	51. 0	13. 0	183	70. 4
20–30 hours	22. 0	2, 256	64. 3	29. 5	12, 199	64. 0	24. 9	56. 4	21. 7
30–40 hours	34. 9	1, 438	41. 0	36. 7	14, 172	74. 3	35. 0	39. 2	15. 1
40–50 hours	47. 0	1, 822	51. 9	46. 2	11, 490	60. 3	47. 0	47. 2	18. 2
50–75 hours	57. 6	1, 418	40. 4	65. 4	10, 221	53. 6	59. 7	32. 0	12. 3
75–100 hours	79. 2	1, 079	30. 7	83. 3	3, 953	20. 7	83. 3	18. 0	6. 92
Over 100 hours	104	725	20. 6	104	3, 591	18. 8	104	8. 5	3. 27
Over 100 hours	131	715	20. 4	116	5, 367	28. 2	131	11. 0	4. 23

The relation of decrease in numbers of bacteria to time of flow from the maximum, as indicated by the percentages remaining at successive time intervals, is by no means regular. Nevertheless, in all three groups, agar counts, gelatin counts, and *B. coli*, it is evident that there is a definite tendency toward a significant decrease with time.

The trend of the data is better shown in Figures 43 and 44, the observations being plotted on logarithmic ordinates in the first of these figures, and on arithmetic ordinates in the latter. The curves in Figure 43 are drawn simply by inspection, but with considerable care, and have been checked by comparing the curves drawn independently by several persons. The curves in Figure 44 have been constructed by scaling off ordinates from Figure 43, as given in Table No. 128. While none of the curves fits the data very closely, it is probable that they indicate the trend of decrease about as well as curves mathematically adjusted to the points. The curves are obviously similar to those derived for the summer months, and might be formulated by the same procedure; but, in view of the character and irregularity of the data, it has not seemed worth while to do this. The ordinates given in Table No. 128 are, therefore, merely values read off from the curves in Figure 43. They serve, however, for identification of the curves, and for comparison with the calculated ordinates of the corresponding curves for summer months, as given in Table No. 125. Comparison with this table shows that the indicated rates of decrease in the gelatin and agar counts in the winter months are decidely less than in the summer months. The rate of decrease in *B. coli* is approximately the same in winter as in summer, up to 50 hours, but beyond that time the decrease is decidedly less rapid in winter.

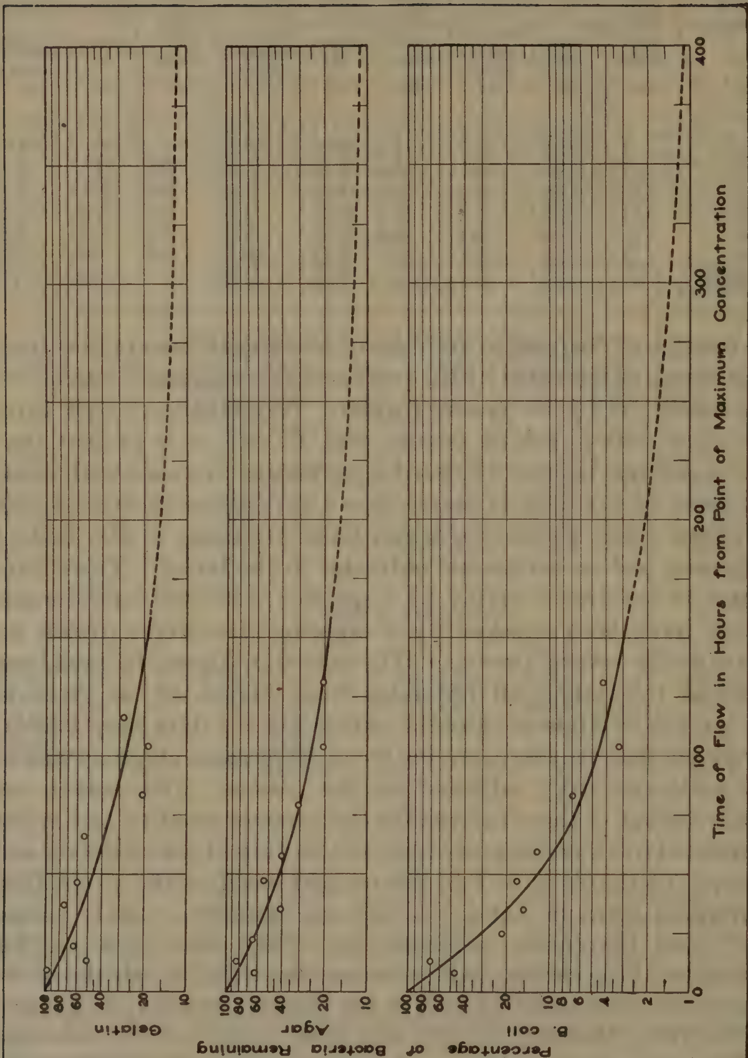

FIG. 43.—Bacterial purification in Ohio River between Cincinnati and Louisville in relation to time of flow from zone of maximum pollution

Gelatin count, agar count, and *B. coli* groups: Winter months, December–March, 1914, 1915, and 1916.
Logarithmic ordinates.
Points (o) indicate actual observations (Table No. 126).

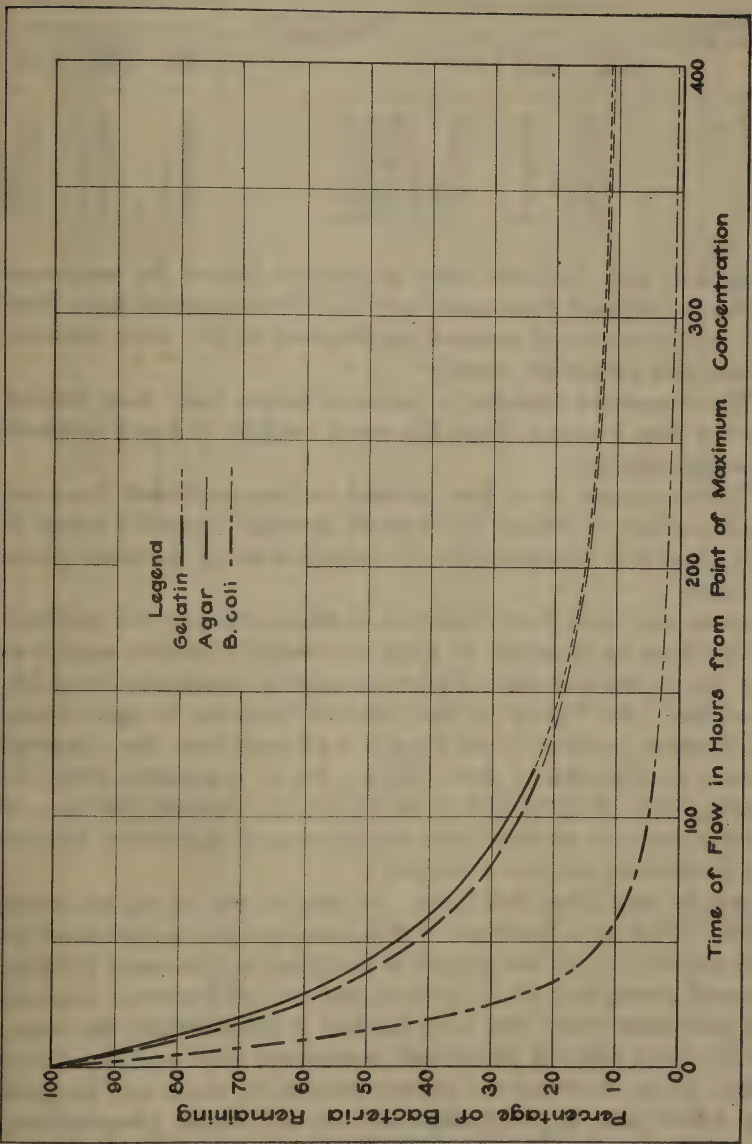

FIG. 44.—Bacterial purification in Ohio River between Cincinnati and Louisville in relation to time of flow from zone of maximum pollution

Gelatin count, agar count, and *B. coli* groups: Winter months, December–March, 1914, 1915, and 1916.
Simple ordinates.
(See fig. 43 for identical data drawn to logarithmic ordinates.)

TABLE No. 128.—*Estimated percentages of bacteria remaining at stated times below section showing maximum count in winter months*

[Ordinates determined graphically from curves in fig. 43]

Times of flow from maximum	Bacteria remaining, percentages of maximum			Times of flow from maximum	Bacteria remaining, percentages of maximum		
	Agar count	Gelatin count	B. coli		Agar count	Gelatin count	B. coli
0 hours	100	100	100	70 hours	33	36	7.3
10 hours	80	82	60	80 hours	30	32.5	6.1
20 hours	67	69	37	90 hours	27.5	29.5	5.3
30 hours	56	59	24	100 hours	25.3	27.0	4.7
40 hours	48	51	16.5	110 hours	23.5	25.0	4.25
50 hours	42	45	12.0	120 hours	22.0	23.0	3.85
60 hours	37	40.5	9.1	130 hours	20.5	21.5	3.50

Comparison with indicated rates of decrease beyond the maximum when time is reckoned from sewer outfalls.—Two methods have been applied to the study of natural purification in the river between Cincinnati and Louisville, namely:

(1) The successive changes in bacterial counts have been related to times of flow reckoned from the sewer outfalls of the Cincinnati metropolitan district.

(2) These changes have been related to time reckoned from the sampling station at which the highest average bacterial count is actually observed, disregarding all observations at sections above this station.

The data used have been otherwise identical and the two methods might therefore be expected to yield substantially similar results as regards the extent and rate of decrease after a maximum count has been reached. In Figure 45 the curve of decrease in agar counts during summer months, when time is reckoned from the observed maximum, as reproduced from Figure 36, is compared with the descending limb of curve (A) from Figure 32, showing the rate of decrease in relation to time from the theoretical maximum, located at 12.5 hours from the sewer outfalls.

As may be seen from this figure, the two curves are by no means identical. They are, however, of the same general significance, so that whichever one of the curves is accepted as the more reliable, the general conception of the extent and rate of bacterial decrease after a maximum count has been reached is substantially the same. About the same order of agreement, sometimes more and sometimes less close, exists between the curves derived by these two methods for the gelatin and *B. coli* groups, and for the winter observations. Therefore, from a broad viewpoint, it is a matter of no great importance which method of grouping the data is used, although, for reasons which have already been stated, we believe that the simpler method of taking the observed maximum as an origin is, on the whole, preferable.

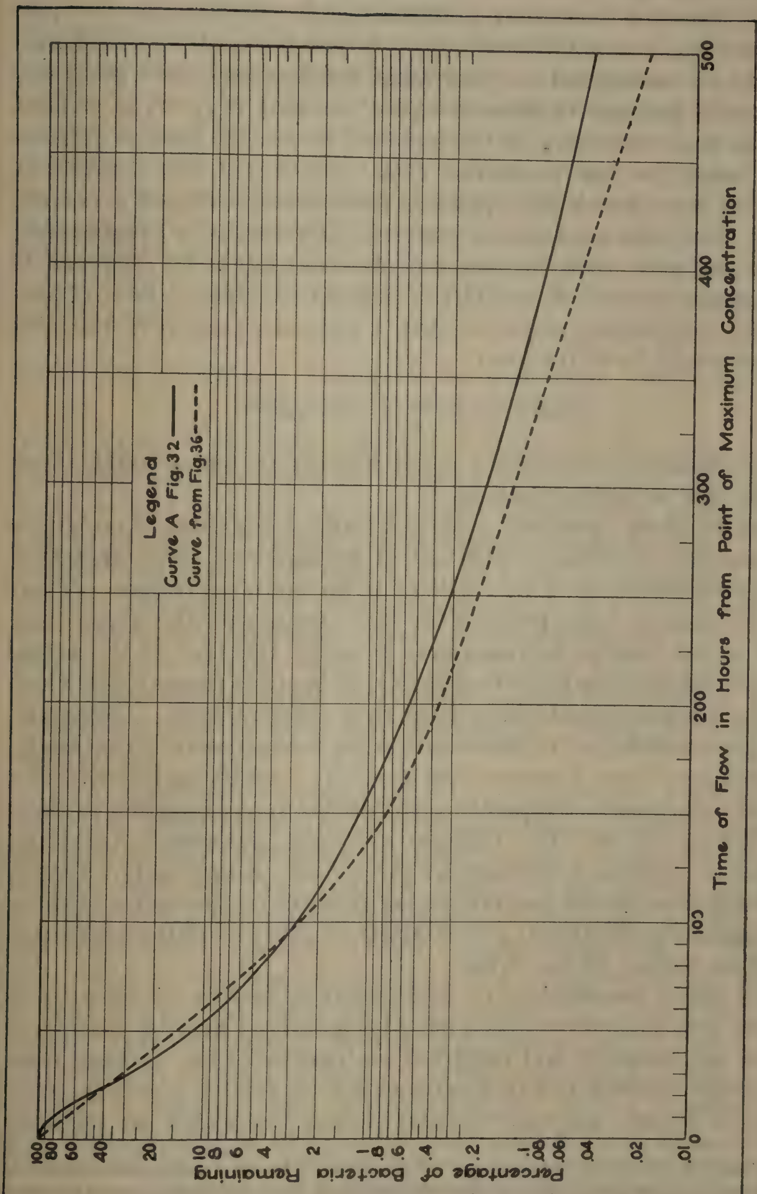

FIG. 45.—Comparison of curves of bacterial purification derived by two methods

Significance of equations representing rates of decrease from the maximum.—Although the equations which have been developed to describe the rates of decrease during the summer months from the zone of observed maximum pollution appear to describe the phenomena with reasonable accuracy, it is not believed that they may properly be considered as expressing fundamental laws governing the rates of decrease of these groups of bacteria in rivers in general, nor even that they state, in fundamental terms, the laws of decrease which apply in this particular river stretch. If the general assumption upon which the equations have been developed is correct, namely, that the numbers of bacteria decrease at a progressively diminishing rate, then the curve of decrease might be supposed to be a composite, not of two but of a great number of lines of successively diminishing slope; so that a general equation of the type adopted would be of the form:

$$y = ae^{-bx} + ce^{-dx} \dots + me^{-nx}$$

Any equation comprising a small number of terms could, therefore, be only an approximation.

It seems likely, however, that this form of equation, even with a large number of terms, is still not of fundamental form, though it might consistently give an excellent fit to the observations. There are, for example, some grounds for the surmise that the diminishing factor in the rate of decrease may be some function of the actual density (numbers per cubic centimeter) of bacteria present,[28] in which case the equation would be written in a different form. Moreover, there are a number of variables not taken into account in this analysis which may have a more or less important modifying influence; for example, changes in temperature within the range included in these data (about 10°–26° C.); changes in depth, quiescence, turbidity, and other physical conditions in the stream, conceivably affecting the death rates of the bacteria either directly or through a primary effect upon the plankton; and climatic or other conditions affecting the whole biology of the stream.

With these possibilities of undetermined factors in view, it is obvious that the curves which have been derived may be considered only as approximate and empirical statements of the average rates of decrease obtaining in this particular river stretch under the conditions of season, temperature, and stream flow which are included

[28] The suggestion that the rate of decrease may be a function of the density of bacteria present is derived chiefly from observations on the rates of purification in the Illinois River, made in the course of a study of that river by the Public Health Service during 1921 and 1922. There is also some suggestive evidence to the same effect in the data of Table No. 114, from which it may be noted that in corresponding periods of time the proportionate decrease in bacteria is greater when the initial counts below Cincinnati are high than when they are low. The suggestion will be further discussed in the report on studies of the Illinois River, which is now in process of preparation.

in the observations. The fact that the Ohio River is a very large stream, a composite of many smaller streams, and that it is generally similar in its physical characteristics and in the range of sewage pollution to a number of other large streams may, however, warrant the surmise that the phenomena of purification in such other streams are generally similar, though doubtless differing more or less in detail. It is evident that any well-founded opinion as to the general applicability of the curves must await the results of comparative studies on other streams; but partial tests of their applicability may be made by comparing them with observations made in the stretch between Portsmouth and Cincinnati, and by testing the reasonableness of results when these curves are applied to estimating the influence of natural purification in the entire river system above certain points.

RATES OF BACTERIAL DECREASE IN THE OHIO RIVER BETWEEN PORTSMOUTH AND CINCINNATI

The rates of bacterial decrease observed in the river between Cincinnati and Louisville may now be compared with observations in the stretch from the junction of the Scioto River, at station No. 358, to the upper limits of Cincinnati, at station No. 461. As has already been noted, this stretch of 103 miles is comparable to that between Cincinnati and Louisville in length and in freedom from any considerable additions of sewage or of tributary inflow which might tend to obscure the influence of natural agencies of purification. However, it differs from the Cincinnati to Louisville stretch in several important particulars, of which the following are the most obvious:

(1) At low river stages the velocity of flow between stations 358 and 461 is much higher than between stations 475 and 598, so that the time of flow through the former stretch is much shorter than through the latter. For example, during the half month, October 1 to 15, 1914, the mean time of flow from station 358 to station 461 was 103.6 hours, corresponding to a mean velocity of 1.0 mile per hour. During the same period the mean velocity between stations 475 and 598 was 0.26 mile per hour, and the time of flow was 470.7 hours. This difference in low-water velocities results largely from differences in channel contour. Between stations 358 and 461 the channel is comparatively uniform and the wetted cross sectional area reduces regularly as the river stage is reduced, whereas, between stations 475 and 598 the low-water channel, especially in the lower half of the stretch, from station 543 to station 598, is broad and flat, with numerous long, quiet pools.

(2) The bacteria present in the river immediately below Cincinnati are very largely (in summer, from 90 to over 99 per cent)

those which have been recently added in the sewage from the Cincinnati metropolitan district. At station 358 the sewage of Portsmouth, Ohio, the nearest sewered community above, is an almost negligible factor in the bacterial pollution, the major sources of sewage pollution being the sewered cities located at very considerable distances upstream, on the Ohio and the Scioto Rivers.

(3) The concentration of bacteria, that is, the number per cubic centimeter, is very much greater in the zone below Cincinnati than at station 358, especially in low-river stages. Thus, during the 4½ months, June 1 to October 15, 1914, the mean agar count at station 358 was 1,420 per cubic centimeter, while at station 475, below Cincinnati, it was 233,000 per cubic centimeter. In winter, and at high-river stages in other seasons, this difference is reduced; but at all seasons the pollution at station 475 is characteristically higher than at station 358.

The observations made at stations 358 and 461, which are given in the basic tabulations of bacteriological data (Tables Nos. 84 and 85) in the form of monthly means, are shown in Table No. 129, regrouped according to gage heights on dates of sampling, with corresponding mean times of flow through the stretch.

TABLE No. 129.—*Detailed summary of bacteriological observations at stations 358 and 461, grouped according to gage heights on dates of sampling*

Gage height		Mean time of flow, station 358 to station 461	Bacteria per cubic centimeter					
			Gelatin counts		Agar counts		B. coli	
Range	Mean		Station 358	Station 461	Station 358	Station 461	Station 358	Station 461
SUMMER MONTHS, APRIL 1 TO OCTOBER 15, 1914 [1]								
2–3 feet	2.3 feet	104.3	652	321	1,098	613	18	9
3–4 feet	3.6 feet	80.1	1,131	868	1,908	971	19	18
4–5 feet	4.3 feet	72.8	833	247	1,211	316	23	6
5–6 feet	5.5 feet	69.0	1,192	312	1,622	472	34	3.6
6–7 feet	6.5 feet	60.3	594	318	1,044	336	29	9
7–8 feet	7.5 feet	55.4	1,391	912	1,524	953	55	14
8–9 feet	8.7 feet	51.5	1,164	792	1,446	2,556	39	34
10–15 feet	11.0 feet	47.3	657	402	624	283	15	7
20–25 feet	22.2 feet	37.2	2,193	1,796	1,438	334	33	22
25–30 feet	27.7 feet	35.0	2,022	2,779	777	632	24	26
30–35 feet	32.6 feet	34.4	2,998	3,886	1,072	1,031	28	16
35 feet and over	42.1 feet	33.5	10,575	6,433	1,952	920	40	39
WINTER MONTHS, JANUARY TO MARCH, 1914 [1]								
Under 15 feet	13.9 feet	43.3			866	394	14	23
15–20 feet	17.5 feet	39.9	8,900	14,560	606	542	13	22
20–25 feet	23.3 feet	36.7	10,280	15,830	1,170	847	23	23
25–30 feet	26.7 feet	35.3	13,970	19,440	1,150	678	31	27
30–35 feet	32.8 feet	34.3	16,980	21,700	2,320	1,590	55	44
Over 35 feet	35.8 feet	33.9	26,800	29,220	833	1,060	37	10

[1] Observations at station 358 begun Jan. 1, 1914; discontinued Oct. 15, 1914.

In the next table, No. 130, the same data are presented in more condensed form, having been summarized by throwing together the observations falling within somewhat broader ranges of gage

height and time of flow. This table shows also the percentages which the bacteria observed at station 461 are of those observed during the corresponding period at station 358.

TABLE No. 130.—*Condensed summary of bacterial counts at stations 358 and 461, grouped according to times of flow between stations, and showing percentages which the counts at station 461 are of those at station 358*

SUMMER MONTHS, APRIL 1 TO OCTOBER 15, 1914

Time of flow from station 358 to station 461		Gelatin count			Agar count			B. coli		
		Station 358, number per cubic centimeter	Station 461		Station 358, number per cubic centimeter	Station 461		Station 358, number per cubic centimeter	Station 461	
Range	Mean		Number per cubic centimeter	Per cent of count at station 358		Number per cubic centimeter	Per cent of count at station 358		Number per cubic centimeter	Per cent of count at station 358
Hours	*Hours*									
Over 70	104.3	652	321	49.2	1,098	613	55.8	18	9	50.0
Do	80.1	1,131	868	76.7	1,908	971	50.9	19	18	94.7
Do	72.8	833	247	29.6	1,211	316	26.1	23	6	26.1
60–70	64.7	893	315	35.3	1,330	404	30.3	32	6.3	19.7
50–60	53.5	1,278	852	66.7	1,485	1,755	118.2	47	24	51.1
40–50	47.3	657	402	61.2	624	283	45.3	5	7	46.7
30–40	35.0	4,447	3,724	83.7	1,320	770	58.3	31	28	91.6

INTER MONTHS, JANUARY TO MARCH, INCLUSIVE, 1914

Hours	*Hours*									
Over 40	43.3	----------	----------	----------	866	394	45.5	14	23	164
30–40	36.0	15,390	20,150	131	1,220	943	77.6	32	25	79.2

As shown in the above table, the tendency is definitely toward a decrease in the bacterial count between stations 358 and 461. This is, however, quite irregular in its relation to times of flow, the most consistent and marked decreases taking place in the time intervals which are intermediate between the extremes. If the attempt be made to relate the ratios of decrease shown in this table to the corresponding times of flow, the data are found to be so irregular that no consistent quantitative relation can be established. Consequently, the phenomena of bacterial decrease in this stretch may be compared with those in the stretch between Cincinnati and Louisville only in a general way.

In Table No. 131 and Figure 46 following, the percentages of bacteria actually remaining at station 461 are compared with the percentages which would have remained at corresponding time intervals had the decrease from station 358 taken place at the rates obtaining for gelatin, agar, and *B. coli* groups, respectively, in the river immediately below the zone of maximum pollution at Cincinnati.[29]

[29] These percentages, which might, of course, be calculated from the formulae given in Table No. 125 have actually been read off graphically from large-scale drawings of Figures 36, 37, and 38.

TABLE No. 131.—*Percentages which the observed counts at station 461 are of those at station 358, compared with percentages expected in corresponding time intervals by applying rates of decrease observed in the river stretch immediately below Cincinnati, summer months, April 1 to October 15, 1914*

Mean time of flow, station 358 to station 461	Percentage of bacteria remaining at station 461					
	Gelatin count		Agar count		B. coli	
	Observed	Calculated	Observed	Calculated	Observed	Calculated
35.0 hours	83. 7	29. 5	58. 3	25. 0	91. 6	21. 0
47.3 hours	61. 2	19. 3	45. 3	15. 7	46. 7	12. 3
53.5 hours	66. 7	15. 7	118. 2	12. 5	51. 1	9. 4
64.7 hours	35. 3	10. 8	30. 3	8. 3	19. 7	5. 9
72.8 hours	29. 6	8. 4	26. 1	6. 2	26. 1	4. 1
80.1 hours	76. 7	6. 7	50. 9	4. 8	94. 7	3. 05
104.3 hours	49. 2	3. 3	55. 8	2. 27	50. 0	1. 18

It is obvious from this comparison that while a fairly consistent reduction in bacteria takes place between stations 358 and 461, the rates of decrease are radically different from those observed in the stretch immediately below Cincinnati.

It has, however, already been noted that between Cincinnati and Louisville the bacterial decrease takes place not at a constant rate, but at a rate which progressively diminishes as the time increases, so that, in the agar count, for example, the percentage of decrease is (see Table No. 125):

In the first 100 hours below the maximum, 97.435 per cent;
In the second 100 hours below the maximum, 86.887 per cent;
In the third 100 hours below the maximum, 66.989 per cent, etc.

As the bacteria present in the Ohio River at station 358 are presumably derived chiefly from sources which are rather remote, both in distance and in time, it may well be supposed that their original initial rates of decrease have already been diminished by the time that they have reached Portsmouth. In such case the low rates of decrease observed between Portsmouth and Cincinnati may be considered as corresponding to the rates of decrease obtaining, not in the upper, but in the lower part of the stretch between Cincinnati and Louisville.

If it were possible to formulate the relation between time and bacterial decrease in the stretch between Portsmouth and Cincinnati, it would be of interest then to compare the curves with the lower segments of the curves of decrease between Cincinnati and Louisville; but, as already stated, the observations between Portsmouth and Cincinnati are not sufficiently regular to permit of any satisfactory formulation. It was at first thought that a longer series of observations in this stretch might yield results of more uniformity; but on further consideration this seems quite doubtful for several reasons, namely:

(1) Since the actual decrease between stations 358 and 461 is evidently not very great, the ordinary observational errors inherent in the methods applied would make the measurement of the differences much less precise than in a case where the actual differences are very great, as between Cincinnati and Louisville.

(2) With a comparatively low bacterial count, tending to be reduced at a low rate, slight increments of pollution from the small communities situated on the river, or from intervening small tributaries, temporarily swollen by local rains, would have proportionately more effect in obscuring the influence of natural purification than in the stretch between Cincinnati and Louisville.

(3) It seems probable that the rate of purification between stations 358 and 461 may actually vary rather widely from month to month, according to the time of flow from upstream sources of pollution to station 358.

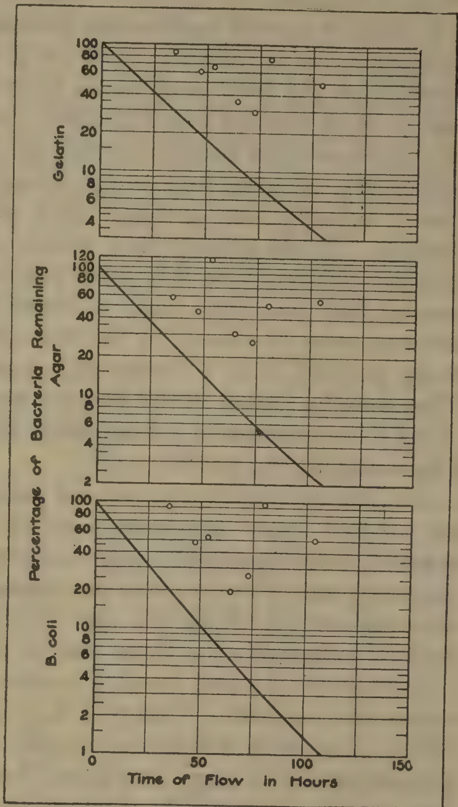

FIG. 46.—Bacterial purification in Ohio River between Portsmouth and Cincinnati compared with curves based on observations between Cincinnati and Louisville.

Summer months: April–November.

Points (o) indicate actual observations at Station 461, above Cincinnati, in relation to time of flow from Station 358, below Portsmouth. Curves are reproduced from Figures 36, 37, and 38, respectively.

On the whole observations in this stretch are, perhaps, not more irregular than is to be expected; and the fact that the rate of decrease is consistently and very greatly lower than in the stretch from Cincinnati to Louisville is consistent with the general law which seems to apply in that stretch; namely, that bacterial decrease proceeds at a rate which diminishes progressively as time from the source of pollution increases.

APPLICATION OF PURIFICATION CURVES TO ESTIMATING THE EXTENT OF NATURAL PURIFICATION BETWEEN GIVEN POINTS ON THE OHIO RIVER

Any laws defining the rates of natural purification are of practical value if they may be applied to estimating, with reasonable precision, the effect of natural purification between a river section and the upstream sources of pollution to which it is exposed. To be of general application the laws must needs be reduced to fundamental terms, and to be of greatest practical value the extent of purification should be related to other variables which can be readily determined without exhaustive investigation, as for example, season, temperature, distance, velocity, and perhaps other physical characteristics of the streams. It has already been indicated that the curves of bacterial decrease derived from this study can not be considered truly fundamental, but that they may, perhaps, be considered as representing average rates of change in the Ohio River and may possibly be of fairly general, even if empirical, application to this river system. They may be tested, in this respect, by applying them to estimating:

(1) The purification taking place from month to month between Cincinnati and Louisville; and

(2) The net purification taking place (a) between Cincinnati and all sewered cities upstream, and (b) between Louisville and all sewered cities upstream from that city. The reasonableness of the estimates may then be tested by comparison with data derived from observations, which in the case of (1) are partially and in (2) are entirely independent of those used in the estimates.

Estimation of mean monthly counts at Louisville, given the actual counts at Cincinnati.—Granting that the curves of bacterial decrease which have been derived accurately describe the average rates of decrease under average conditions obtaining during winter and summer periods, respectively, it does not necessarily follow that they are applicable even to the river stretch between Cincinnati and Louisville under all conditions, even within the range included in the processes of averaging. Still less does it follow that they are equally applicable throughout the entire range of physical conditions. It might readily happen, for instance, that differences in rates of decrease associated with differences in river stage or temperature have been obscured by the averaging processes.

A test from this point of view may be made by comparing the mean counts actually observed from month to month at Louisville (station 598) with calculations based upon the observed counts in the zone immediately below Cincinnati, and the actual mean times of flow through the stretch. As will be seen by reference to Table No. 110 (p. 269), conditions as to both temperature and stream flow varied quite widely from month to month, the range of temperatures

being from 8.3 to 27.3° C., and of river stages from 2.8 to 32.7 feet; also that the combinations of stream flow and temperature are quite varied.

Table No. 132 shows such a comparison with respect to agar counts at Station 598 during each of the months April to November, inclusive, in the three years 1914, 1915, and 1916. From the maximum count observed in each month below Cincinnati, whether at station 475, 482, 488, or 492, and the mean time of flow from that section to station 598, the expected percentage remaining at the latter has been read off from a large-scale reproduction of Figure 36; and the expected count at station 598 has been calculated by applying this percentage to the observed count at the upper station.[30]

TABLE No. 132.—*Numbers of bacteria actually observed at station 598 (Louisville) compared with numbers calculated from observations at Cincinnati, by months, April to November, 1914, 1915, 1916* [1]

Month	Origin, station No.[1]	Time of flow, origin to station 598	Bacteria per centimeter			Difference (a)−(b), per cent of (a)
			At origin below Cincinnati [1]	At station 598		
				(a) Calculated [1]	(b) Observed	
November, 1914	475	282.3	198,000	307	124	+59.61
August, 1914	475	235.1	262,000	642	1,250	−94.70
October, 1914	475	234.0	203,000	507	700	−38.07
September, 1914	475	210.0	170,000	547	506	+7.50
November, 1916	482	185.0	118,700	522	800	−53.26
September, 1916	475	196.5	151,900	577	800	−38.65
July, 1914	475	197.1	147,000	559	203	+63.69
June, 1914	475	166.0	237,000	1,363	586	+57.01
October, 1916	475	165.4	216,100	1,264	800	+36.71
April, 1915	488	102.0	78,400	1,881	220	+88.30
August, 1916	482	103.8	97,350	2,239	5,100	−127.78
July, 1916	475	107.0	86,700	1,820	4,100	−125.27
September, 1915	488	95.4	54,900	1,647	2,880	−74.86
November, 1915	482	93.0	88,700	2,838	3,360	−18.39
May, 1915	488	86.9	58,400	2,248	3,450	−53.46
August, 1915	492	82.4	64,200	2,889	2,810	+2.73
October, 1915	482	78.8	70,900	3,615	3,070	+15.08
June, 1915	488	70.1	35,900	2,477	3,220	−30.00
July, 1915	475	75.7	57,300	3,208	4,500	−40.27
May, 1916	492	55.9	37,600	4,324	2,800	+35.25
June, 1916	492	51.1	32,600	4,499	4,800	−6.69
May, 1914	492	47.6	39,500	6,044	2,780	+54.00
April, 1916	492	36.5	5,800	1,363	2,000	−46.73
April, 1914	492	33.9	7,440	1,957	3,250	−66.07

[1] Calculations based on number of bacteria per cubic centimeter (agar count) observed at station showing maximum count, time of flow being reckoned from this origin.

The agreement between calculated and observed values, as shown in the table, may be considered quite close, notwithstanding that the deviations in some instances are in excess of 100 per cent; for even in these cases the calculated and observed counts are of the same general order of magnitude. Considering that from month to month the actual monthly mean counts vary, at the origin, from 5,800 to 262,000 per cubic centimeter and at station 598 from 124 to 5,100 per cubic centimeter, closer agreement of the calculated results could hardly be expected.

[30] More precise values could be derived by solving the equation given in Table No. 125 for the given time (x); but the simple graphical method is sufficiently accurate for present purposes.

Examination of the table shows further that the positive and negative deviations between calculated and observed counts are of nearly though not precisely the same frequency (10 positive vs. 14 negative); that they approximate a normal distribution;[31] and that there is no tendency for the errors to be greater in the upper and lower portions of the table, which represent the extremes of variation in stream-flow, than in the middle section, which represents more nearly average conditions. The standard deviation of the differences between calculated and observed values is 60.9 per cent. The probable error is therefore ±41 per cent, and 11 out of the 24 deviations actually fall within this range. It appears, therefore, that this curve is applicable to a rather wide range of stream-flow conditions, and that calculations based upon it may be expected to check reasonably with actual observations.

The demonstration of such a definite relationship between the degree of pollution at Cincinnati and that at Louisville would seem to make it possible to forecast, with sufficient exactness for practical purposes, the effect which a given increase in the population of the Cincinnati metropolitan district will have upon the bacteriological quality of the Ohio River water at Louisville. This is in itself a matter of considerable importance in relation to plans for the future control of the sewage pollution in this stretch.

Estimates of net purification in river system above Cincinnati and Louisville, respectively.—The Ohio River at station 461, immediately above the city of Cincinnati, is exposed to direct sewage pollution from all sewered communities which discharge their sewage into the river or its tributaries above this section. The sewered population on the watershed above Cincinnati, as estimated from a careful survey in 1915, was about 2,372,000, distributed, according to distance by river from Cincinnati, approximately as shown in Table No. 133, in which this population is grouped in 50-mile distance zones from station 461.[32]

Taking the mid-point of each distance zone as the mean distance between the sewered communities of that zone and station 461, the corresponding mean times of flow from each zone to this station, as given in the same table, have been estimated for the months April to November, 1914, and for the corresponding period of 1915. For communities situated directly upon the Ohio, these estimates of time are fairly well based, having been carefully computed from the velocities corresponding to the mean of daily gauge heights actually recorded in successive prisms of the river during the two periods. But since no data are available as to velocities in the tributary streams, it has been assumed that they are the same as in the main stream. The time intervals are, therefore, necessarily quite rough estimates.

[31] $\frac{\text{Mean deviation}}{\text{Standard deviation}} = 0.84.$

[32] See also Table No. 43, p. 45.

The percentages of sewage bacteria expected to survive after a time interval corresponding to the mean time of flow from each distance zone has been determined graphically from the curves shown in Figures 36, 37, and 38. By applying these percentages, the actual sewered population in that zone has been reduced to terms of "equivalent population" at station 461. For instance, in the distance zone 150–200 miles above Cincinnati the actual sewered population as given in Table No. 133 is 244,700, and the mean time of flow during the months April to November, 1914, is estimated at 115 hours. According to Figure 36 (based on Table No. 125) 2.45 per cent of the bacteria of the agar count group may be expected to survive after 115 hours. Therefore as regards bacterial pollution (agar count) at station 461, the actual sewered population of 244,700, at a distance of 115 hours, is equivalent to a population of $244,700 \times 0.0245 = 5,995$ discharging sewage into the river immediately above that section.

The populations in the various distance zones, thus reduced to "equivalent populations" at station 461, with respect to the agar count, gelatin count, and *B. coli* groups of bacteria, are then summed up, giving the totals shown at the bottom of the table.

A tabulation of the actual sewered population above Louisville, similarly reduced to terms of "equivalent population" discharging sewage immediately above that city, at station 598, is shown in Table No. 134. It will be observed that the distribution of the actual sewered population above Louisville is quite different from the distribution above Cincinnati, in that the sewered population within 200 miles above Louisville is much in excess of that within the same distance above Cincinnati.

TABLE No. 133.—*Summary of actual sewered population in successive distance zones above Cincinnati (station 461) and of calculated equivalent population with respect to bacterial pollution at station 461, April–November, 1914 and 1915*

Zones, distance above station 461	Actual sewered population (1915)	Estimated mean time of flow in hours to station 461, April-November		Equivalents of sewered population discharging sewage into river immediately above station 461 as calculated in terms of—					
				Gelatin count		Agar count		B. coli	
		1914	1915	1914	1915	1914	1915	1914	1915
0– 50 miles	1, 900	14	11	1, 160	1, 270	1, 090	1, 220	990	1, 140
50–100 miles	7, 100	42	34	1, 600	2, 170	1, 340	1, 870	1, 060	1, 570
100–150 miles	32, 300	76	59	2, 450	4, 170	1, 820	3, 300	1, 180	2, 360
150–200 miles	244, 700	115	88	6, 000	12, 970	4, 090	9, 300	2, 000	5, 630
200–250 miles	41, 300	156	116	410	970	280	670	124	326
250–300 miles	63, 200	196	145	320	780	240	530	114	234
300–350 miles	32, 200	236	174	100	235	78	164	43	74
350–400 miles	140, 100	285	212	260	570	207	436	138	217
400–450 miles	131, 100	341	252	145	350	115	271	97	160
450–500 miles	1, 186, 400	396	286	770	2, 220	611	1, 760	640	1, 210
500–550 miles	153, 900	446	317	62	215	50	169	63	129
550–600 miles	149, 400	489	341	40	164	32	131	49	111
600–650 miles	80, 000	532	365	14	70	11	55	20	51
650–700 miles	62, 000	575	389	7	43	6	34	12	35
700–750 miles	38, 100	618	413	3	21	2	17	6	19
750–800 miles	9, 000	651	437	1	4	0	3	1	4
Total[1]	2, 372, 700			13, 300	26, 200	9, 970	19, 900	6, 540	13, 300

[1] Total in round numbers.

TABLE No. 134.—*Summary of actual sewered population in successive distance zones above Louisville (station 598) and of calculated equivalent population with respect to bacterial pollution at station 598, April to November, inclusive, 1914 and 1915*

Zones, distance above station 598	Actual sewered population (1915)	Estimated mean time of flow to station 598 (hours)		Equivalents of sewered population discharging sewage into river immediately above, as calculated in terms of—					
				Gelatin count		Agar count		B. coli	
		1914	1915	1914	1915	1914	1915	1914	1915
0– 50 miles	800	25	24	332	344	300	312	260	276
50–100 miles	200	71	61	18	25	13	19	9	14
100–150 miles	532, 000	112	91	14, 100	25, 800	9, 630	18, 190	4, 840	10, 640
150–200 miles	121, 800	147	117	1, 420	2, 840	974	1, 950	428	938
200–250 miles	70, 700	176	140	502	962	354	658	159	293
250–300 miles	51, 200	210	165	220	430	165	297	82	133
300–350 miles	20, 400	251	194	55	106	43	80	25	37
350–400 miles	245, 400	291	223	440	896	361	707	238	358
400–450 miles	72, 100	332	252	86	186	67	145	54	86
450–500 miles	26, 600	372	281	22	52	17	39	16	27
500–550 miles	138, 400	421	319	71	190	57	149	65	115
550–600 miles	774, 000	477	358	232	720	188	573	271	511
600–650 miles	604, 100	532	393	105	405	94	320	154	332
650–700 miles	106, 900	582	424	12	53	10	43	21	49
700–750 miles	162, 200	625	448	12	64	10	52	25	66
750–800 miles	63, 400	668	472	3	20	3	16	8	21
800–850 miles	83, 900	711	496	3	21	2	17	8	26
850–900 miles	9, 000	754	520	0	2	0	2	1	2
Total [1]	3, 083, 100			17, 600	33, 100	12, 300	23, 600	6, 660	13, 900

[1] Totals in round numbers.

It is impossible to check these estimates of "equivalent population" in any precise way, but their reasonableness may be tested by comparing them with estimates made by a different method and using independent data.

It has been shown (see Tables Nos. 100, 101, and 102 and adjacent text) that the total number of bacteria added to the Ohio River in its passage past Cincinnati, when expressed in quantity units (bacteria per cubic centimeter × discharge in second-feet ÷1,000) was fairly constant during corresponding seasonal periods of the three years 1914, 1915, and 1916. The averages for the months April to November, inclusive, for the three-year period were, in terms of:

		Quantity units
(1)	Gelatin count	2, 948, 000
	Agar count	3, 458, 000
	B. coli	94, 400

The sewered population of the Cincinnati metropolitan district being about 494,300, these totals correspond to the following quantities per thousand of sewered population:

		Quantity units per 1,000
(2)	Gelatin count	6, 037
	Agar count	6, 995
	B. coli	191

As these values correspond in a general way with those derived from observations at Louisville during the year 1914, they may be taken, in the absence of better evidence, as representing the *average* ratios of sewage bacteria to contributing sewered population.[33]

[33] These figures have since been checked with similarly calculated values for the Chicago sanitary district and found to be in substantial agreement.

Multiplying the mean counts actually observed each month at stations 461 and 598, respectively (See Table No. 84), by the corresponding mean discharges, and averaging the products, it is found that the mean quantities of bacteria carried by the river at these sections for the months April to November, inclusive, were:

(3)

	Quantity units (bacteria per cubic centimeter ×discharge in second-feet÷ 1,000)	
	1914	1915
Station 461:		
Gelatin count	179, 650	254, 800
Agar count	38, 000	124, 700
B. coli	1, 260	3, 930
Station 598:		
Gelatin count	212, 830	309, 870
Agar count	180, 770	232, 840
B. coli	6, 190	4, 460

From these data, and those given above, calculations have been made of the sewered populations that would have been required to contribute the quantities of bacteria actually observed at stations 461 and 598, assuming that their sewage was discharged immediately above these sections, and that the river was subject to no pollution from other sources. The estimates thus made are compared, in Table No. 135, with those previously made by the method shown in Tables Nos. 133 and 134.

TABLE No. 135.—*Bacterial pollution of the Ohio River immediately above Cincinnati (station 461) and Louisville (station 598), respectively, expressed in terms of equivalents in sewered population discharging sewage into the river immediately above*

As estimated independently by two methods, namely:

(A) From theoretical rates of bacterial decrease, applied to actual sewered populations on watershed above each city, in accordance with estimated mean times of flow.

(B) From mean bacterial counts and discharge of river as actually observed at stations 461 and 598, respectively, during periods designated.

[Estimates are means for the months April to November, inclusive, 1914 and 1915]

Bacteriological determination used as basis for estimate	Equivalents of sewered population			
	At station 461		At station 598	
	(A)	(B)	(A)	(B)
1914				
Gelatin count	13, 300	29, 800	17, 600	35, 300
Agar count	9, 970	5, 430	12, 300	25, 800
B. coli	6, 540	6, 590	6, 660	[1] 32, 400
Means	9, 936	13, 940	12, 187	31, 167
1915				
Gelatin count	26, 200	42, 200	33, 100	51, 300
Agar count	19, 900	17, 800	23, 600	33, 300
B. coli	13, 300	20, 600	13, 900	23, 300
Means	19, 800	26, 867	23, 533	35, 967

[1] This figure is very largely influenced by the observations in one month, April, 1914, when the highest discharge of the year coincided with a high *B. coli* count, which, in turn, resulted from exceptional results on two days. A more representative mean value would be about 15,000.

When the estimates made by the two methods are compared item by item, the result by method (B) is found, in several instances to be about twice as great as by method (A); and in one instance the result by method (B) is nearly five times that indicated by method (A). Nevertheless, considering that the "equivalent populations" shown in the table are the residuals of actual populations, amounting to 2,372,000 above Cincinnati, and 3,083,000 above Louisville, and that these populations are distributed in a complex manner, at distances ranging from less than 25 miles to more than 800 miles above these cities, the substantial agreement between the two methods is far more striking than any discrepancies in detail. This is shown better when the method of expression is inverted, to show the percentage reduction in bacterial pollution attributable to the agencies of natural purification, as in the following summary:

TABLE NO. 136.—*Percentage reduction in bacterial pollution at station 461, above Cincinnati, and station 598, above Louisville, attributable to agencies of natural purification*

Comparison of estimates by methods (A) and (B), as in Table No. 135.
Calculations based on means of estimates in terms of gelatin counts, agar counts, and *B. coli*.
Months, April to November, inclusive, 1914 and 1915.

Year	Percentage reduction			
	At station 461		At station 598	
	Method (A)	Method (B)	Method (A)	Method (B)
1914	99.58	99.41	99.60	98.99
1915	99.16	98.87	99.24	98.83

As shown by this table, the bacterial reduction ranges from 98.83 to 99.60 per cent; and the greatest difference between results by the two methods in any instance is 0.61 per cent. It seems safe to conclude, then, that when applied to estimating the net purification taking place in all stretches of the Ohio River above Cincinnati or Louisville, the formulæ describing rates of bacterial decrease give results which are entirely reasonable, and quite in accordance with all the facts available as to the actual pollution of the river.

In view of the fact that the formulæ which have been used are obviously not in fundamental form, it would hardly be expected that they would be applicable at all to even a crude measurement of such complex phenomena as the purification taking place between a given point on the river and all the scattered sources of sewage pollution upstream. However, the agreement between the calculations thus made and the observed bacterial pollution at Cincinnati and Louisville is not merely accidental, as indicated by the fact that the agreement holds at two different sections, stations 461 and 598, and

in two separate periods characterized by quite different conditions of stream flow. Also it has been found, by additional calculations which are not reproduced here, that estimates applied to briefer periods representing, respectively, lower and higher mean river stages, give results which are still in reasonable conformity to the observed pollution at stations 461 and 598.

The explanation suggested is that the rates of bacterial decrease in different stretches of the river system actually do vary, being perhaps higher than indicated by these formulæ in such very highly polluted zones as are found in small tributaries which receive the sewage of fairly large cities; and lower in the less polluted zones in large streams immediately below the sewer outlets of small communities. It would appear, however, that the rates of decrease applied uniformly in these calculations are representative average rates; so that errors of calculation for individual stretches tend to be compensating, giving results which are approximately correct when many separate estimates are summed up, as in Tables Nos. 133 and 134, though the calculations for individual distance-zones may be greatly in error.

Any detailed analysis of the figures given in Table No. 135 is of doubtful value; but it may be of interest to note certain tendencies, which are at least suggestive. The two methods (A) and (B) which have been applied to estimating "equivalent populations" at Cincinnati and Louisville are consistent in indicating that the pollution, whether measured in terms of the gelatin count, agar count or *B. coli* is higher (with one exception) at Louisville than at Cincinnati, and higher at both stations in 1915 than in 1914. In general, the pollution, as actually observed (method B) at stations 461 and 598, is greater than is indicated by the process of "stepping down" the actual sewered population. This might be expected on two grounds, namely:

(1) The estimates made by method (A) take no account of bacteria derived from sources other than urban sewage. While evidence has already been given (Table No. 99) that the bacteria found in the Ohio River immediately below large cities consist chiefly of those recently added in sewage, it does not follow that this ratio holds in more distant zones, or that the bacterial pollution from surface drainage is negligible.

(2) It has already been noted that the actual rates of bacterial purification at times beyond about 300 hours are probably less than indicated by the formulæ which are used.

Estimates of natural purification in winter months.—Applying the curves shown in Figure 43, representing more or less hypothetically, the rates of decrease in the gelatin count, agar count, and *B. coli* groups in winter, estimates of net bacterial purification above Cin-

cinnati and Louisiville during the winter months, January, February, March, and December, 1914 and 1915, have been made by the same methods applied to similar estimates for the summer period. The results are shown in Tables Nos. 137 and 138. These estimates are then compared with estimates based upon actual bacterial counts and discharge during these periods as shown in Table No. 139, which corresponds to Table No. 135.

TABLE No. 137.—*Summary of actual sewered population in successive distance zones above Cincinnati (station 461) and of calculated equivalent population with respect to bacterial pollution at station 461, winter months, December to March*

Zones distance above 461	Actual sewered population, 1915	Estimated mean time of flow in hours to station 461 Dec., Jan., Mar.		Equivalents of sewered population discharging sewage into river immediately above station 461 as calculated in terms of—					
				Gelatin count		Agar count		B. Coli	
		1914	1915	1914	1915	1914	1915	1914	1915
0–50 miles	1, 900	10	9	1, 600	1, 600	1, 560	1, 560	1, 200	1, 200
50–100 miles	7, 100	28	27	4, 330	4, 400	3, 820	3, 850	1, 880	1, 920
100–150 miles	32, 300	47	45	15, 200	15, 500	14, 000	14, 500	3, 650	4, 520
150–200 miles	244, 700	67	63	90, 500	94, 400	83, 200	88, 100	18, 800	21, 300
200–250 miles	41, 300	88	82	12, 400	13, 200	11, 600	12, 200	2, 270	2, 480
250–300 miles	63, 200	108	100	16, 000	17, 060	15, 200	16, 100	2, 720	2, 970
300–350 miles	32, 200	128	118	6, 990	7, 500	6, 700	7, 150	1, 160	1, 260
350–400 miles	140, 100	149	138	26, 000	28, 100	25, 900	27, 400	4, 110	4, 490
400–450 miles	131, 100	171	158	22, 300	23, 600	22, 200	23, 600	3, 280	3, 670
450–500 miles	1, 186, 400	192	177	183, 900	193, 000	186, 000	197, 000	26, 100	28, 500
500–550 miles	153, 900	211	194	22, 600	23, 500	22, 800	23, 900	3, 000	3, 230
550–600 miles	149, 400	229	210	20, 900	22, 400	21, 100	22, 100	2, 660	2, 910
600–650 miles	80, 000	246	225	10, 900	11, 400	11, 000	11, 400	1, 300	1, 440
650–700 miles	62, 000	263	241	8, 180	8, 490	8, 310	8, 490	949	1, 040
700–750 miles	38, 100	280	256	4, 910	5, 070	4, 880	5, 140	549	598
750–800 miles	9, 000	297	272	1, 130	1, 170	1, 110	1, 170	123	135
Total	2, 372, 700	------	------	447, 840	470, 390	439, 380	463, 660	73, 751	81, 663

TABLE No. 138.—*Summary of actual sewered population in successive distance zones above station 598 and of calculated equivalent population with respect to bacterial pollution at station 598, winter months, December to March*

Zone distance above station 598	Actual sewered population, 1915	Estimate of mean time of flow in hours to station 598 Dec., Jan., Mar.		Equivalents of sewered population discharging sewage into river immediately above station 598					
				Gelatin count		Agar count		B. coli	
		1914	1915	1914	1915	1914	1915	1914	1915
0–50 miles	800	12	10	640	656	616	640	432	472
50–100 miles	200	34	31	118	111	106	112	40	47
100–150 miles	532, 000	55	50	227, 000	241, 000	207, 000	223, 000	54, 800	63, 300
150–200 miles	121, 800	75	69	42, 000	44, 800	38, 100	40, 800	8, 160	9, 010
200–250 miles	70, 700	94	87	20, 400	21, 600	18, 900	40, 800	3, 600	3, 960
250–300 miles	51, 200	113	105	12, 500	13, 300	18, 900	12, 500	2, 120	2, 280
300–350 miles	20, 400	133	123	4, 280	4, 590	4, 120	4, 410	697	765
350–400 miles	245, 400	153	141	45, 400	49, 100	44, 700	47, 600	7, 090	7, 800
400–450 miles	72, 100	173	159	1, 180	12, 600	11, 700	12, 500	1, 740	1, 930
450–500 miles	26, 600	194	178	4, 120	4, 360	4, 150	4, 390	572	638
500–550 miles	138, 400	215	197	29, 100	21, 200	21, 500	20, 300	2, 630	2, 920
550–600 miles	774, 000	236	217	107, 000	111, 000	108, 000	113, 000	13, 200	14, 500
600–650 miles	604, 100	257	236	79, 700	83, 400	80, 900	84, 600	9, 480	10, 300
650–700 miles	106, 900	277	254	13, 900	14, 200	13, 900	14, 400	1, 560	1, 710
700–750 miles	162, 200	294	269	20, 600	21, 200	19, 900	21, 200	2, 240	2, 430
750–800 miles	63, 400	311	285	7, 860	8, 110	7, 610	7, 990	836	900
800–850 miles	83, 900	328	300	10, 200	10, 600	9, 900	10, 200	1, 060	1, 130
850–900 miles	9, 000	345	316	1, 080	1, 110	1, 040	1, 070	109	117
Total, miles[1]	3, 083, 100	------	------	629, 000	662, 000	605, 000	639, 000	110, 000	124, 000

[1] Totals in round numbers.

TABLE No. 139.—*Bacterial pollution of the Ohio River immediately above Cincinnati (station 461) and Louisville (station 598), respectively, expressed in terms of equivalents in sewered population discharging sewage into the river immediately above*

[As estimated independently by two methods, namely:
(A) From theoretical rates of bacterial decrease, applied to actual sewered populations on watershed above each city, in accordance with estimated mean times of flow.
(B) From mean bacterial counts and discharge of river at stations 461 and 598, respectively, during periods designated.
Estimates are means for the months December, January, February and March, 1914 and 1915.]

Bacteriological determination used as basis for estimate	Equivalents of sewered population—			
	At station 461		At station 598	
	(A)	(B)	(A)	(B)
1914				
Gelatin count	448, 000	2, 460, 000	629, 000	3, 940, 000
Agar count	439, 000	309, 000	605, 000	1, 520, 000
B. coli	73, 800	80, 700	110, 000	182, 000
Means	320, 300	949, 900	448, 000	1, 880, 700
1915				
Gelatin count	470, 000	1, 640, 000	662, 000	3, 000, 000
Agar count	464, 000	760, 000	639, 000	1, 110, 000
B. coli	81, 700	128, 000	124, 000	155, 000
Means	338, 600	842, 700	475, 000	1, 421, 700

The estimates made by the two methods show distinctly wider divergences than in the case of similar estimates for the summer months. Considering means derived from gelatin counts, agar counts, and *B. coli*, the bacterial pollution observed at stations 461 and 598 is from 2.4 to 4.2 times as great as is indicated by applying rates of decrease to actual sewered populations. This would seem to indicate either that the rates of purification applied are too high or that a large proportion of the bacteria present are from sources other than urban sewage. Or it may be that both of these explanations apply in some degree. In view of the fact that all the bacteriological observations made in the winter months show marked irregularities, and are more or less unsatisfactory, closer agreement than shown was hardly to be expected. It may be noted, however, that all the estimates made in terms of *B. coli* are in fairly close agreement, which suggests that even in winter, the *B. coli* found in the river may be derived largely from urban sewage; also that the curve describing the rate of decrease in *B. coli* may be more reliable than the curves based on gelatin and agar counts.

The evidence of these tables confirms the conclusion previously drawn from analysis of observations in winter, namely, that the rates of bacterial purification during winter months are much reduced as compared with the rates during spring, summer, and autumn. However, when it is considered that the run-off from the watershed is greatly increased during the winter, presumably adding to the river a much larger proportion of bacteria from sources other than urban sewage, it is not safe to conclude, even in the case of the gelatin count group, that the agencies of natural purification are inactive, or that their influence is in any sense negligble.

APPENDIX

METHODS EMPLOYED IN THE COLLECTION AND EXAMINATION OF SAMPLES

COLLECTION OF SAMPLES

Samples for bacteriological examination were collected in wide-mouthed glass-stoppered bottles of about 150 c. c. capacity, sterilized by dry heat, after being wrapped in heavy paper, with a tin-foil cap over the stopper and mouth. During the first three months of study, from January 1 to April 1, 1914, the bacteriological samples were taken from just below the surface by plunging an open bottle into the stream to a depth of about 2 feet. Subsequently the bacteriological samples were all taken at mid-depth, using various types of apparatus which permitted the sample bottle to be opened at the desired depth.

Samples for determination of dissolved oxygen were collected in bottles of 250 c. c. capacity, with well-ground, accurately fitting glass stoppers. The collector used was so designed that the sample bottle received a volume of water equal to three times its capacity, thus completely replacing the first volume received, which would be in contact with the air contained in the bottle. These samples were always collected in duplicate, to provide one sample for immediate titration and another for incubation to determine the oxygen loss. They were always taken at mid-depth, the collector being so constructed that no inflow took place until a stopcock had been opened, by pulling on a control line after the collector had been lowered to the desired depth.

Samples for sanitary analysis were collected in glass-stoppered bottles of 2,000 c. c. capacity, carefully cleaned but not sterilized.

The small portions needed for making up monthly composites for mineral analysis and for daily determinations of turbidity and alkalinity were ordinarily taken from the bacteriological sample bottles after the bacteriological examinations had been made.

Great care was exercised in the selection and instruction of the personnel to whom the collection of samples was entrusted, and there is reason to believe that all collections were made with unusual care and conscientiousness.

LABORATORY METHODS

All laboratory procedures followed in making physical, chemical and bacteriological examinations were based upon the standard methods prescribed by the laboratory section of the American Public Health Association.[1] However, as to certain tests, alternative procedures are given in the above-cited standard reference; and as to others the procedure actually followed in this study differed more or less from the prescribed standard. Consequently, it seems desirable, as a record for future reference, to identify the procedure used in each determination by reference to the Standard Methods, and by noting all departures therefrom.

[1] Standard Methods for the Examination of Water and Sewage, Am. Pub. Health Assoc., New York, 2d ed., 1912. All reference to "Standard Methods" refer to this edition unless otherwise stated.

PHYSICAL EXAMINATION

Turbidity.—For samples of low turbidity (less than about 25), comparison with silica standards in Nessler tubes. For samples of higher turbidity, a candle turbidimeter was used, each instrument having been carefully calibrated against standard silica suspensions. Both procedures in accordance with Standard Methods.

Color and odor.—Not determined.

SANITARY CHEMICAL ANALYSIS

1. *Nitrogen as free ammonia.*—By distillation method, using permanent standards for comparison, as prescribed in Standard Methods.

2. *Nitrogen as albuminoid ammonia.*—As prescribed in Standard Methods. Determination discontinued August 31, 1914.

3. *Total organic nitrogen (including free ammonia).*—A sample of 250 c. c. was digested with 4 c. c. of concentrated H_2SO_4 until the digestate was colorless. A crystal of $KMnO_4$ was then added, and after this was taken up 250 c. c. of redistilled water was added. The whole was then made alkaline with NaOH, and 150 c. c. distilled over. After mixing, 25 c. c. of the distillate was diluted to 50 c. c. and Nesslerized. With each set of samples a blank determination was made under exactly similar conditions. The reading from the blank was recorded and subtracted from that for each sample to give the final corrected result.

After July 1, 1915, direct Nesslerization of the digestate was employed, a blank determination being made with each set of samples.

4. *Nitrogen as nitrate.*—Procedure as described in Standard Methods, using permanent fuchsine standards, but modified in that turbid samples were clarified by adding 2 c. c. of a 10 per cent solution of aluminium sulfate and 5 drops of a 10 per cent solution of potassium hydrate to about 400 c. c. of the sample, after which 100 c. c. of the clarified sample was withdrawn with a pipette for testing.

5. *Nitrogen as nitrate.*—Phenolsulphonic acid method, as described in Standard Methods

6. *Oxygen consumed.*—Procedure as presented in Standard Methods; digestion in steam bath for 30 minutes. To each sample, before digestion, was added an amount of distilled water equal to the amount used in the blank determination.

7. *Dissolved oxygen.*—Determined by the Winkler method, as described in Standard Methods, the only modifications being (*a*) the addition of 1 c. c. of concentrated sulfuric acid instead of 2 c. c. of a 1:1 dilution for the titration of iodine; and (*b*) taking 100 c. c. of the contents of the sample bottle for titration after addition of the reagents.

8. *Biochemical oxygen demand.*—At the time when these studies were in progress the determination of biochemical oxygen demand was not included in Standard Methods, and the procedure followed therefore requires some explanation, though it was substantially in accordance with that described in the Standard Methods of 1923 ("dilution method," pp. 76–78).

Samples for this determination were collected in duplicate. The dissolved oxygen content of one sample was determined immediately. The duplicate sample, tightly sealed, was incubated for 24 hours at 20° C., after which its content of dissolved oxygen was determined. The difference—that is, the loss of oxygen on incubation, which is called the "24-hour demand"—is taken to represent a fairly constant fraction (about 20.5 per cent) of the "total oxygen demand," which would be satisfied usually in about 20 days at 20° C.

In the samples examined, from the Ohio River and its tributaries, the dissolved oxygen initially present was almost invariably sufficient to leave a reserve

of oxygen after 24 hours' incubation; hence it was not necessary to dilute the samples or to add sodium nitrate.

When samples were collected at temperatures below 20° C., it was necessary to take special precautions to avoid error due to release of oxygen at the higher (20°) temperature of incubation. The device adopted was as follows: The glass stopper in the bottle to be incubated was removed and replaced with a stopper made of a short length (about 6 inches) of glass tubing, with a collar of heavy rubber tubing of such size as to fit closely into the mouth of the bottle. Thus, the glass tube projected into the bottle, and extended 2 inches or more above the mouth. A small surface of water—the area of a cross-section of the glass tube—was consequently exposed to the air, but this was so small as to be negligible. Any air released during incubation, rising to the highest portion of the bottle or collecting in small bubbles adhering to the sides, was retained.

At the completion of the 24-hour incubation period the bottle was removed from the incubator, care being taken to avoid jarring. The water in the tube generally stood a little above the top of the bottle. Where air bubbles had collected on the inside of the tube within the bottle, the tube was flooded with tap water, the finger placed tightly over the top of the tube to avoid entrance of air, the bottle inverted, and gently tapped against the edge of the workbench. This detached such air bubbles as were adhering to the sides of the tube and allowed them to rise and collect with the remainder of the air in the bottle. The bottle was then turned upright again, and about the same amount of water as had been added was "flipped" out.

Grasping the rubber collar tightly with the thumb and forefinger of one hand the large tube was carefully drawn up until the greater part of its length projected above the mouth of the bottle, great pains being taken not to break the tight joint between the rubber collar and the bottle. The joint between the rubber collar and the tube was loose enough for the latter to slide readily without loss of air. The tube, in this position, had capacity sufficient to avoid any loss of liquid during the addition of the reagents. A small pipette carrying the $MnSO_4$ solution was then introduced through the tube into the bottle, delivery being made first at a point near the bottom and a few drops finally at the top to catch any oxygen still inside the tube. Then 2 c. c. of KOH–KI reagent was added; first a few drops near the top, to react with the liquid inside the tube, and the rest well toward mid-depth.

After the addition of the reagents the long tube was again pushed down into the bottle until the liquid just overflowed the top. The top of the tube was covered tightly with the finger, in such way as to prevent the entrance of any air, and the bottle well shaken to bring the entrapped air into intimate contact with the reagents. The bottle was then allowed to stand five minutes to settle, after which the agitation was again repeated but in such way as to produce a swirling motion. This was followed by a second settling period of five minutes, the precipitate, excepting small amounts which might have remained inside the tube, collecting in the bottom of the bottle.

Again drawing the tube upward, 1 c. c. of concentrated H_2SO_4 was added through the tube, the point of delivery being near the top, to allow for dissolving any manganic hydrate which might have adhered to the inner walls of the tube.

Without disturbing the bottle contents the tube stopper was carefully withdrawn and the glass stopper replaced. When this was correctly done the liquid displaced by the glass stopper was not sufficient to introduce any appreciable error into the results.

After the glass stopper had been replaced the contents of the bottle were thoroughly mixed and 100 c. c. withdrawn for titration with $Na_2S_2O_3$. Since there was no loss of liquid during the addition of the reagents, no correction for the reagents was applied.

MINERAL ANALYSIS

1. *Residue on evaporation* (*total, volatile, and fixed*).—As prescribed in Standard Methods.

2. *Total hardness*.—Determined until July 1, 1914, by the "soap method"; after July 1, 1914, by the soda-reagent method, both procedures in accordance with Standard Methods.

3. *Alkalinity*.—Procedure with methyl orange as described in Standard Methods, 1923, page 37. The use of methyl orange as an indicator was not recommended in the Standard Methods of 1912, but was adopted in this study because this indicator appeared to be more satisfactory than erythrosine or lacmoid in the examination of the turbid waters encountered.

Additional determinations, using phenolphlthalein as the indicator (in the cold) were made in the examination of samples from the upper Ohio and from some of the tributaries. Standard Methods, 1912.

4. *Acidity*.—Tests were made as prescribed in Standard Methods, titrating with N/50 sodium carbonate solution in the presence of (*a*) methyl orange, (*b*) phenolphthalein cold, and (*c*) phenolphthalein at boiling temperature.

5. *Noncarbonate* (*incrustant*) *hardness*.—Calculated as the difference between total hardness and alkalinity, as allowed by Standard Methods.

6. *Chlorine as chlorides*.—Procedure as in Standard Methods. Concentration of the samples was not found necessary.

7. *Sulfates*.—The method employed for this determination, which was designed to be a rapid estimation rather than a refined analytical determination, was a modification of a turbidimetric method outlined by Jackson,[2] and by Muer,[3] for the estimation of sulphur in coal. In this method, 100 c. c. of the water was first acidified with 1 c. c. of 1:1 hydrochloric acid, followed by addition of 5 c. c. of a 10 per cent barium chloride solution. This was allowed to remain (occasionally mixing carefully with a glass stirring rod), for three minutes, after which the turbidity was read with the candle turbidimeter. The amount of sulfates present (as SO_4) was then read from a calibration curve obtained with known amounts of Na_2SO_4. When the sample of water examined was turbid, it was first filtered through fine filter paper. If any turbidity remained in the filtrate, its amount was determined with the turbidimeter, and the same filtrate was then used for the sulfate estimation. The final reading was then corrected for the initial turbidity of the filtrate.

8. *Calcium* (*Ca*).—The method used for this determination was substantially that which has been outlined by Hale.[4] One hundred c. c. of the water was acidified with acetic acid, heated to boiling, and 5 c. c. of a saturated solution of ammonium oxalate slowly added. The beaker was then placed in a water bath for about a half hour, after which the precipitate was collected in a Gooch crucible. This was carefully washed with hot water, and the Gooch crucible was placed in the original beaker. Then 10 c. c. of 1:1 sulphuric acid was added and, after a short time, 100 c. c. of hot water. The free oxalic acid was then titrated with a standardized potassium permanganate solution and the calcium estimated.

9. *Iron* (*Fe*).—Procedure as outlined in Standard Methods, using the potassium sulphocyanide method. Usually only the total iron was determined, although in special instances both dissolved and suspended iron were determined. Ferrous iron was not determined.

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[2] Journal of the American Chemical Society, Vol. 33, p. 799.

[3] Journal of Industrial and Engineering Chemistry, August, 1911.

[4] Journal American Chemical Society, July, 1907.

BACTERIOLOGICAL METHODS

All the culture media used in this study were prepared in the central laboratory at Cincinnati, whence they were shipped weekly to the subsidiary laboratories. The media used and the methods of preparation, which conformed substantially to those prescribed in the Standard Methods of 1912, were as follows:

Nutrient gelatin.—Prepared from meat infusion in accordance with Standard Methods, except that 12.5 per cent of undried gelatin was added instead of 10 per cent of desiccated gelatin. Also, up to June, 1915, the medium was heated for a longer period than prescribed in Standard Methods, this being found necessary to insure its sterility in the large (2 liter) containers in which shipments were made to branch laboratories. Subsequently, after June 1, 1915, smaller containers (flat flasks) were used for shipment and the period of sterilization was reduced to that recommended in Standard Methods. It appears from comparative tests that the medium subjected to prolonged heating gave plate counts about 20 per cent lower than those obtained with gelatin prepared in strict accordance with Standard Methods.

Nutrient agar.—Prepared from meat infusion in accordance with Standard Methods, except that 1.25 per cent of undried thread agar was added instead of 1 per cent of the desiccated.

Endo's medium.—A 3 per cent agar, made with 1 per cent of Liebig's meat extract. Reaction adjusted to be neutral to phenolphthalein. To each 100 c. c. of the melted medium, when ready for use, were added 1 gram of C. P. lactose in sterile solution; 0.5 c. c. of a saturated (10 per cent) solution of basic fuchsin in 95 per cent alcohol; and 0.125 gram anhydrous sodium sulfite, dissolved in distilled water.

Lactose broth.—Prepared from meat infusion in accordance with Standard Methods, except that muscle sugar was removed by inoculation with a pure culture of *B. coli.*

Beginning in May, 1915, lactose broth was made with 0.3 per cent of Liebig's extract instead of meat infusion, a long series of comparative tests having shown that this substitution would make no material change in results.

Special care was taken to avoid the inversion of lactose, by reducing to a minimum the period of heating after addition of the sugar.

Plate counts.—Three gelatin and three agar plates were made from each sample, the amounts planted varying from 1 c. c. to 0.0001 c. c., according to the bacterial content of the sample. Two of the plates in each set of three were planted with an amount such as might be expected to give not less than 25[5] nor more than 400 colonies per plate. The third plate was planted with one-tenth or ten times this amount, according as it appeared more probable that the duplicate plates might show too many or too few colonies for a reliable count. It was thus possible to obtain in each series at least one, usually two plates, with a good distribution of colonies.

Special care was taken to attain and check exactness in making dilutions and in measuring portions for plating.

Quantitative determinations of B. coli.—Portions constituting a geometrical series were planted in lactose fermentation tubes, which were incubated at 37° C. for 48 hours to test gas formation. In order that the tests might have quantitative significance, the amounts planted were of such range that in each sample the largest amount would almost invariably give a positive[6] and the smallest a negative result. This involved testing always as many as three, frequently as many as five, portions of each sample.

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[5] Except where 1 c. c. of the sample gave less than 25 colonies, as amounts larger than 1 c. c. were not planted.

[6] Except where amounts of 10 c. c. were not uniformly positive.

In the confirmation of positive and doubtful presumptive tests, the procedure followed conformed essentially to that prescribed for the "partially confirmed test" in Standard Methods, editions of 1917, 1920, 1923; that is, in the smallest portion showing gas in each sample, the test was carried to the point of demonstrating the growth of "typical" colonies on Endo's medium, or, in the absence of such colonies, was carried to the point of demonstrating the presence or absence of organisms growing aerobically on plates and forming gas on subsequent transfer to lactose bouillon fermentation tubes.

In addition, every tenth consecutive positive partially confirmed test was carried further to full confirmation in order to establish an index of the significance of the partially confirmed tests. It was thus found that 96 per cent of these partially confirmed tests were positive according to the "completed test." It is believed, therefore, that the results as recorded have substantially the same significance as if they had been carried, in every case, to full confirmation by the "completed test."

The mean numbers of *B. coli* per c. c., or so called "B. coli index," as recorded in the tables presented in this report have been computed according to the procedure described in Standard Methods (1917, 1920, and 1923), this being considered the method best adapted to summarizing the results of long series of tests in portions of varying size into simple figures. That this method is fully justified and gives results which are relatively if not absolutely correct, is attested by the consistency with which variations in the B. coli index follow variations in simultaneous gelatin and agar plate counts.

RELATED PUBLICATIONS

The following publications on stream pollution and closely related subjects have been issued by the Public Health Service, and may be obtained without cost upon request so long as the supply lasts. The asterisk (*) indicates that the stock has been exhausted, but the publications so marked may be bought from the Superintendent of Documents, Washington, D. C., if the prices are given:

PUBLIC HEALTH BULLETINS

74. Investigation of the pollution of tidal waters of Maryland and Virginia, with special reference to shellfish-bearing areas. By Hugh S. Cumming. 1916. 199 pages.
86. Investigation of the pollution of certain tidal waters of New Jersey, New York, and Delaware, with special reference to bathing beaches and shellfish-bearing areas. By Hugh S. Cumming. 1917. 147 pages.
87. Stream pollution. A digest of judicial decisions and a compilation of legislation relating to the subject. By Stanley D. Montgomery and Earle B. Phelps. 1917. 408 pages.
97. Studies on the treatment and disposal of wastes: I. The treatment and disposal of strawboard waste, by Harry B. Hommon. II. The determination of biochemical oxygen demand of industrial wastes and sewage, by Emery J. Theriault and Harry B. Hommon. 1918. 56 pages; 8 plates.
100. Studies on the treatment and disposal of industrial wastes: III. The purification of tannery wastes, by Harry B. Hommon. (Final Report. See Public Health Bulletin No. 97.) 1919. 133 pages.
101. Studies of methods for the treatment and disposal of sewage. Treatment of sewage from single houses and small communities. By Leslie C. Frank and C. P. Rhynus. 1919. 117 pages.
109. Studies on the treatment and disposal of industrial wastes: IV. The purification of creamery wastes. By Harry B. Hommon. 1921. 87 pages.
118. Studies on the treatment and disposal of industrial wastes: V. The purification of tomato-canning wastes. By Harry B. Hommon. 1921. 59 pages.
131. A study of the pollution and natural purification of the Ohio River. I. The plankton and related organisms. By W. C. Purdy. 1923. 78 pages.
132. Studies of representative sewage plants. By E. J. Theriault and H. H. Wagenhals. 260 pages.

HYGIENIC LABORATORY BULLETINS

*77. Sewage pollution of interstate and international waters, with special reference to the spread of typhoid fever. I. Lake Erie and the Niagara River. By Allan J. McLaughlin. 1911. 169 pages. 25 cents.

78. Report No. 4 on the origin and prevalence of typhoid fever in the District of Columbia (1909). By L. L. Lumsden and John F. Anderson. (Including articles contributed by Thomas B. McClintic and Wade H. Frost. 1911. 196 pages. 27 charts. 15 maps.

89. Sewage pollution of interstate and international waters, with special reference to the spread of typhoid fever. VI. The Missouri River from Sioux City to its mouth. By Allan J. McLaughlin. 1913. 84 pages.

104. Investigation of the pollution and sanitary conditions of the Potomac watershed, with special reference to self-purification and the sanitary condition of shellfish in the lower Potomac River. By Hugh S. Cumming. Plankton studies by W. C. Purdy and hydrographic studies by Homer P. Ritter. 1916. 231 pages, 23 plates.

REPRINTS FROM PUBLIC HEALTH REPORTS

*181. The pollution of tidal waters. Bearing on health and the importance of control. By Hugh S. Cumming. April 10, 1914. 11 pages. 5 cents.

*204. What is a safe drinking water? By Allan J. McLaughlin. June 26, 1914. 11 pages.

214. Studies on the self-purification of streams. By Earle B. Phelps. August 14, 1914. 7 pages.

225. The chemical disinfection of water. By Earle B. Phelps. October 9, 1914. 10 pages.

232. Bacteriological standard for drinking water. Treasury Department standard for drinking water supplied by common carriers. November 6, 1914. 8 pages.

*362. The sewage pollution of streams. By W. H. Frost. September 15, 1916. 12 pages. 5 cents.

384. Control of pollution of streams. The International Joint Commission and the pollution of boundary waters. By Earle B. Phelps. January 26, 1917. 8 pages.

496. Treatment and disposal of creamery wastes. By Earle B. Phelps. December 6, 1918. 5 pages; 1 plate.

*504. The treatment of sewage from single houses and small communities. By Earle B. Phelps. February 14, 1919. 6 pages. 2 plates. 5 cents.

576. Ultra-violet rays in water purification. December 12, 1919. 4 pages.

580. Treatment and disposal of sewage. By H. B. Hommon, J. K. Hoskins, H. W. Streeter, R. E. Tarbett, and H. H. Wagenhals. January 16, 1919. 31 pages.

581. Prevention of stream pollution by dye and intermediate wastes. By E. J. Casselman. January 23, 1920. 19 pages.

594. A further study of the excess oxygen method for the determination of the biochemical oxygen demand of sewages and industrial wastes. By E. J. Theriault. May 7, 1920. 11 pages. The determination of the biochemical oxygen demand of sewage and industrial wastes. By E. J. Theriault and H. B. Hommon. October, 1918. 16 pages.

737. The loading of filter plants. By H. W. Streeter. March 31, 1922. 13 pages.

813. An experimental study of the relation of hydrogen ion concentrations to the formation of floc in alum solutions. By Emery J. Theriault and W. Mansfield Clark. February 2, 1923. 20 pages.

828. Indicators for pH control of alum dosage. By Barnett Cohen. April 6, 1923.

844. The principles underlying the movement of bacillus coli in ground water, with resulting pollution of wells. By C. W. Stiles and Harry R. Crohurst. June 15, 1923. 6 pages.